

GEOLOGY

CHAPTERS OF EARTH HISTORY

—
GEORGE HICKLING M.Sc.

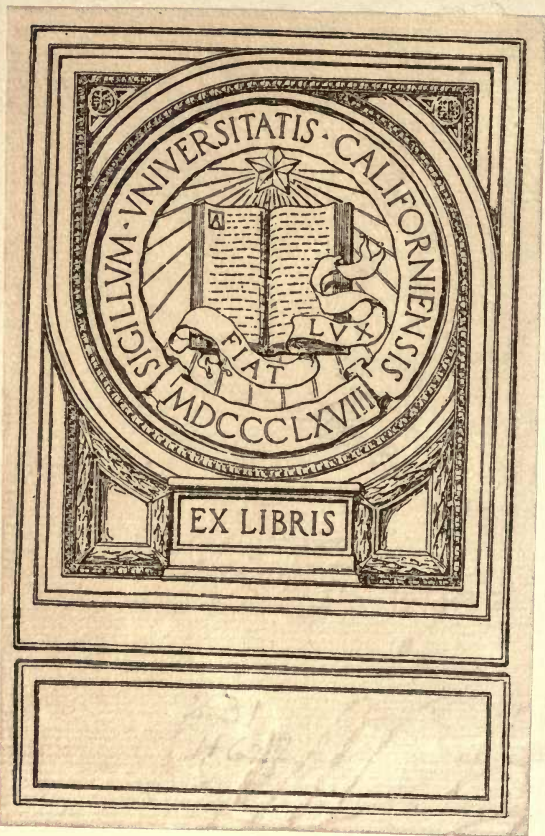
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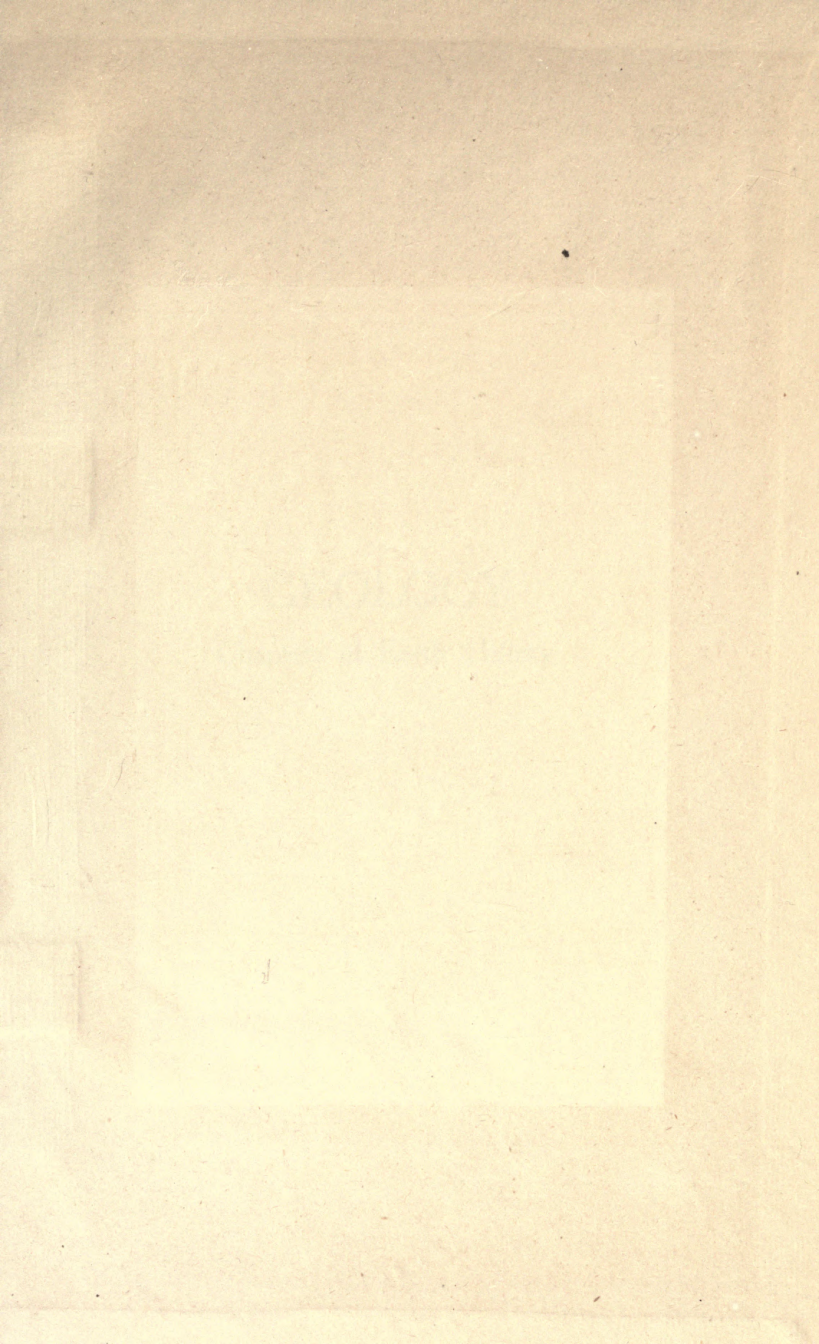


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GEOLOGY

Chapters of Earth History



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[Keeler.

THE "WHIRLPOOL" NEBULA. M.51 *Canum Venaticorum*.

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Plate I.]

[Geology, frontispiece.

GEOLOGY

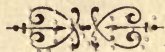
Chapters of Earth History

BY

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Illustrated



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CONTENTS



	PAGE
INTRODUCTION	1
CHAPTER I.—THE ORIGIN OF THE EARTH ...	5
II.—VOLCANOES AND EARTHQUAKES...	25
III.—THE SOLID ROCKS	42
IV.—EARTH SCULPTURE	55
V.—THE SEA-FLOOR	70
VI.—MOUNTAIN BUILDING	81
VII.—THE PHYSICAL HISTORY OF BRITAIN	97
VIII.—THE HISTORY OF LIFE ON THE EARTH	116

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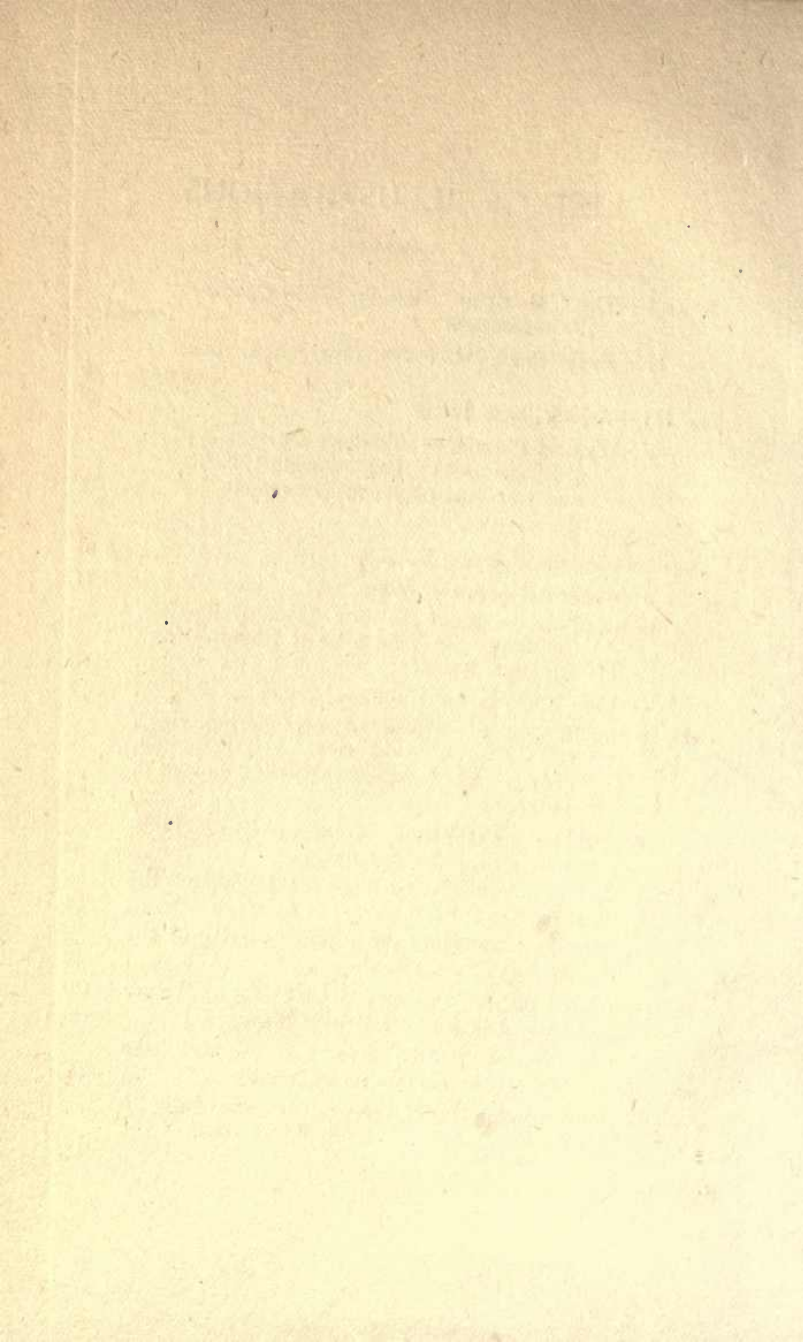
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LIST OF ILLUSTRATIONS

Plate I.—The “Whirlpool” Nebula. M.51 <i>Canum</i> <i>Venaticorum</i> <i>Frontis.</i>	
II.—Eruption of Mt. Peleé, Martinique, 1902 <i>facing p.</i>	28
III.—Atemir, near Settle „	59
IV.—Typical Fossils. 1, Trilobite crustacean ; 2, Brachiopod ; 3, Cephalopod ; 4, Echi- noid ; 5, Gastropod ; 6, Pelecypod „	116
Fig. 1—Ideal Section of a Volcano p	31
2—Aughros Head, Co. Sligo	41
3—(A) Thin Slice of Granite from Dalbeattie, Scotland. (B) Thin Slice of Rhyolite from Elfdalen, Sweden	45
4—Lion Rock, Isle of Cumbrae, Clyde	51
5—(A) Portion of course of meandering river. (B) Course of same river at later period, changed by erosion of banks and deposit of sediment	68
6—Fold in rocks forming cliff west of Little Hang- man Hill, near Ilfracombe	89
7—Section illustrating the gentle folding of the rocks in the South-east of England	91
8—Section illustrating the intense folding of the rocks in the Grampians	91
9—Rocks on shore at Siccar Point, Berwickshire	101
10—Geological Map of the British Isles	104
11—Skeleton of Brontosaurus, a Deinosaur, from the Upper Jurassic of Wyoming	125
12—(A) Development of the skull of the Elephant. (B) Development of the limbs and teeth of the Horse	130



INTRODUCTION



THE tale has gone the rounds of the aged Abbé who, being accosted wandering alone among the mountain wilds, answered the inquiry how he came to be there with the story of a dream he had had during the course of a fever which he had believed to be mortal. In his vision he was asked by his Maker what he thought of the beautiful world in which he had been permitted to live. The question was a revelation to him. He, who had spent his life exhorting his fellows to look to the beauties of a future world, had never thought to look around him. He could make no answer. But, when he awoke, he made a vow that if he should still be permitted to live he would devote his grey years to an inspection of the world. Health returned, and so he was found upon his pilgrimage.

The story has become a favourite, because few can read it without sympathy. How many could give account of the beauties of the world in which they live? It is recorded here because it expresses eloquently, if unconventionally, the import of that much-misunderstood word, Science. For it is the whole object of science to *know* the beauties of the world around us; not only the world as it is to-day

but as it has been in the past, also. It is the special province of Geology to recover the story of the earth's past, to show through what vicissitudes it has attained its present condition. In all ages and all climes, from the earliest dawn of human civilisation, man has sought to know how the world came to be. Not only had the Jews their story of Creation, but similar legends are found among the oldest writings and traditions of many nations of antiquity. Whether Geology or Astronomy is the older science can never be known, both having their roots deep in the lost grounds of early human history. Indeed, in the earlier ages, they were not two sciences, but one. Cosmogony was alike the foundation of them both. Various causes during the chequered history of science led to their gradual separation, notably the recognition of the true place of the earth in the universe, and in modern times, the intense reaction against the wild speculations of the Middle Ages, which led geology to repudiate all concern with the *origin* of the earth, and to confine her attentions to its history since it became a globe such as we now know it. But the step was a mistaken one, and geology is rapidly returning to her old alliance. She has been true long enough to her old watchword that the Present is the key to the Past, and is beginning to realise again that it is even more profoundly true that the Past is the key to the Present. Yet the exigencies of our position compel us always to work from the present to the past; and while the

astronomer, by observing the present condition of other worlds throws light on the past of our own, it is by carefully noting how changes proceed around us to-day that we are able to interpret the changes which have clearly occurred in the past. Thus, occupying an intermediate position between Astronomy, with the unfathomable universe for its fields, on the one hand, and the many sciences which seek to investigate the varied manifestations of life and matter in our own world on the other, Geology seeks to apply the truths gathered by them all to the interpretation of the past history of the earth recorded by Nature herself in the rocks at our feet. It is, therefore, the most comprehensive of all the sciences. To the geologist, the world of to-day, with all its varied aspects of being and doing, is but a momentary glimpse of Nature in her grand progress of evolution through illimitable time.

The foregoing indication of the wide scope of our subject should sufficiently indicate why we have chosen to entitle this little volume "*Chapters of Earth History.*" So manifold and so diverse are the branches into which the study of geology divides itself that no volume, however large, can give a complete account of the whole, even in outline. Nor is a systematic account our intention; but rather to glance at the subject from various points of view, so that, without detaining ourselves for a minute inspection of any aspect, we may gain a general impression of the whole. As we have seen that

speculations concerning the origin of the world attracted attention ages before any other geological theme, we may believe that the same question will still afford the surest foothold for the interest of the general reader. Following a brief account of that subject, we must see how the rocks around us may be made to disclose their history, watch them crumbling under the beat of wind and rain, see their remains buried under the sea and raised again to form new lands. We shall see in the incessant, though imperceptible, heavings of the earth's crust, the power which reproduces the lands which the elements destroy; in the volcano and earthquake its visible manifestation. In the concluding chapters we will endeavour to trace something of the history of our own country and of that strange succession of extinct creatures which peopled the world in past ages.

The chief hope of the writer is that this brief sketch may do something to add to the reader's interests by enabling him to find greater meaning in the scenes around him. The great merit of geology is its power to attract its followers out into the country, to find food for the mind as well as exercise for the body among the sea-cliffs and on the mountain-side. However delightful the works of the great pioneers of the science may be to occupy the leisure hours at home—and they form no mean contribution to the literature of the past century—it is in the field that they acquire their full meaning and their fit surroundings. Probably no other science is so well calculated to form a healthy and manly hobby; none, certainly, is better fitted to enlarge one's perception of the beauties of Nature, to lead one to a truer realisation of the littleness of human concerns.

GEOLOGY

Chapters of Earth History



CHAPTER I

THE ORIGIN OF THE EARTH

OUR knowledge of the true place of the earth in the universe has been acquired only after many centuries of patient search. Even so far back as the time of Hipparchus—perhaps long before—men had realised that the earth was a spherical body. The constantly circular horizon at sea, the circular shadow of the earth whenever it was seen projected on the moon during an eclipse, did not hide their meaning from the ancients. Some fair approach to accuracy was attained in the measurement of the diameter of the earth nearly two thousand years before it was destined to be circumnavigated. Measurement of the apparent height of the sun above the horizon in different parts of Egypt at the same time provided the necessary data. For the apparent elevation depends, of course, on the latitude; hence if it is found, for example, that two places (one directly north of the other) are 1 degree apart, and the distance in miles be measured, mere multiplication of the latter distance by 360 is required to give the circumference of the earth, assuming it to be really a sphere. Even the distance of the moon was approximately known to the Greeks, and

consequently something of the size of that body. Hipparchus himself devised a method for estimating the distance of the sun. The difficulty of the necessary observations (on the length of the various phases of the moon) defeated his aims, though he was enabled to conclude that the distance could not be under 3,000,000 miles, and the sun, therefore, a body many times larger than the earth. Ages earlier, the ancient star-watchers of the East had picked out those five "stars" which are distinguished from all the hosts of the sky by their *wandering* habits, changing their places night after night among the true or "fixed" stars. Observation even permitted them to conclude that two of these "planets" (Greek—a wanderer), viz, Venus and Mercury, were bodies which circled round the sun, and were therefore at times nearer than that body, while the remaining three, Mars, Jupiter and Saturn, were more distant; and that furthest of all were the stars. But, having gone so far, human prejudice barred the way to further progress; no mind was yet free enough to escape the conviction that the earth must be the centre of the universe. Whatever advance had been made towards a true estimate of the relative dimensions of the earth and the space and bodies around it, the essential belief still remained that this globe was in the fullest sense the centre of all creation. Hence arose those complicated schemes which sought to explain the observed motions of the sun, moon and planets on the assumption that they all moved round the earth. It can scarcely be necessary to record how this "Ptolemaic" system of astronomy was implicitly believed for upwards of fifteen hundred years, until Copernicus, in 1543, announced his discovery that all the observed phenomena were

explained quite simply if it were assumed that the earth itself is a planet revolving annually round the sun. The story of the persecution of the followers of Copernicus for this appalling "heresy" is only too well known, but it is worth recalling in order to emphasise the real magnitude of this step towards the realisation of the earth's true place. The earth was "degraded" to be a mere satellite of the sun, and but one of six, at that.

Now this great barrier was passed, progress was rapid. It was soon possible to draw a map of the "Solar System," showing the paths of the various planets round the sun, and their *relative* distances, with great accuracy. Kepler's discovery of the laws of planetary motion, and Newton's of gravitation followed quickly. The invention of the telescope at once led to the recognition of the fact that the other planets were spherical bodies like the earth. But still the *scale* of the system was only vaguely known. The distance from us to any other planet, once determined, would give all the information required—the other distances would be known at once. Yet so great is the space separating us from our nearest planetary neighbour that only within the last century and a half have even approximate measurements been attained, while not more than thirty years have elapsed since measurements worthy to be called accurate have been available. Even now there remains a substantial margin of uncertainty. Thus, while our mean distance from the sun is certainly very near 92,900,000 miles, we cannot be sure it may not be two or three hundred thousand miles more or less. In other words, there may be a doubt of about one half per cent on the whole distance. Happily this small uncertainty is of no moment from our

present point of view. We now know the scale of the Solar System with ample accuracy to allow us to view the earth in its true relations to the other members. It will materially assist our subsequent discussion if we here append a table giving the relative sizes of the various planets and their distances from the sun.

TABLE OF THE SOLAR SYSTEM.*

	Mean distance from Sun Miles	Mass	Density	
		Earth=1	Water=1	Earth=1
SUN ...		329,390	1.40	0.25
MERCURY ...	36,000,000	0.055?	5.56?	1.00?
VENUS ...	67,200,000	0.807	5.14	0.93
EARTH ...	92,900,000	1.000	5.56	1.00
MARS ...	141,600,000	0.106	3.92	0.71
MINOR PLANETS...				
JUPITER...	483,300,000	314.50	1.37	0.25
SATURN ...	886,200,000	94.07	0.64	0.12
URANUS...	1,782,800,000	14.40	1.35	0.24
NEPTUNE ...	2,793,500,000	16.72	1.29	0.23

Two large planets now appear in the system which were unknown to the ancients, being very remote and consequently too faint to be seen without a telescope. Uranus was added upwards of a century ago (1781) by Herschell, Neptune in 1846 as one of the greatest triumphs of mathematical astronomy, its existence and position being predicted simultaneously and independently by Adams and Leverrier, from a study of the disturbing effects of its attraction on the movements of Uranus. In addition, a host of "minor" planets swarm between the orbits of Mars and Jupiter. They already number near six hundred, and year by year more fall into the traps set for them.

* From Ball, *Spherical Astronomy*.

Looking over the preceding table, certain facts stand out prominently. All the bodies in the system—even the sun itself—are minute compared with the distances between them. Should we construct a model in which the sun was represented by a 2-foot globe, the earth would figure as a pea about 70 yards away. Neptune would be distant nearly a mile and a quarter! Again, the planets fall readily into two groups as regards size; near the sun are the four small planets, among which we have to number the earth. The outer planets are far grander in their proportions. In the same model which has a pea to represent the earth, Jupiter would be a good-sized orange. Yet all the planets rolled together would be quite insignificant compared with the sun. As to the six hundred minor planets, they could not build up the earth between them.

We must now compare the earth in certain other respects with its neighbours. Mars and Jupiter will be selected, since they may be taken as typical of the rest, and are much better known than the others. Mars is a globe whose diameter is a little more than half that of the earth. Viewed with a first-class telescope at a time when it is nearest to the earth, it presents an appearance not unlike that of the full moon as seen with the naked eye or with an opera-glass. The light and dark areas are, of course, different in form; they have perhaps more of a rude resemblance to the form of the continents and oceans on the earth. And land and water they have long been supposed to represent, with the more plausibility, in that the darker areas have a greenish tinge while the brighter ones are distinctly reddish, giving to the planet its well-known ruddy light, the light which it reflects from the sun. It is not possible as yet either

to confirm or deny this old interpretation of the appearance, though recent observations, as well as certain theoretical considerations, throw considerable doubt on its correctness. It may be well to recollect that in the case of the moon the dark areas were always held to be oceans until our telescopes clearly demonstrated that there is not a particle of water on its surface. On Mars, however, we observe something certainly not to be paralleled on the moon. Over each of its poles there is a snow-white cap, reminding us irresistibly of the snowy coverings around the terrestrial poles. In this matter we are able to make an observation which gives us greater confidence. Mars has its seasons like our own, and it is regularly observed that as each Martian pole in turn approaches its summer, its white cap diminishes in area, while the winter is marked by its increase. Here we seem to have a clear parallel to the annual retreat and advance of our own polar ice. That we are really dealing with ice and snow seems to admit of little doubt. It has been suggested that the ice may not be frozen water, but some other substance. There is, however, no evidence that such is the case, and it is not probable.

The so-called "canals" of Mars are so familiar that they cannot be entirely passed over. Let us begin by saying that any marking on that planet less than ten miles in width would almost certainly be invisible with the best telescopes under the finest conditions. That *some* long, straight markings exist on its surface is undoubted. Whether the multitude of finer "canals" which make up the wonderful network reported by some observers have any real existence cannot yet be settled. If they have, they enable us to draw at least one useful conclusion, for

some of them *cross the "seas."* Should this observation be confirmed we shall have destroyed the oceans of Mars, though the nature of the "canals" will be as problematical as before.

The question of an atmosphere on Mars is likewise involved in uncertainty. It seems fairly evident that if the planet were supplied with air as abundant and moist as that round the earth, it would make itself more conspicuous than it does. On the other hand, some observers have believed that they have observed slight changes of appearance to be attributed to masses of cloud. Certainly slight changes do occur in the aspect of the planet from time to time, which are not easily interpreted apart from an atmosphere of some kind. If the conclusion favoured by the balance of evidence is correct, that the atmosphere is much more rarified than our own, then that is a further reason for doubting the existence of true seas on the planet, for the average temperature would probably be so low that any water present would normally exist as ice.

It is much to be regretted that we cannot at present speak with more certainty of Mars, for it is a body of unusual interest from our present point of view. But let us mark the fact that so far as the evidence goes, it points to a state of affairs intermediate between those of the Earth and the Moon. While its atmosphere and surface-water are probably less abundant than on the Earth, they do not appear to be entirely absent as in the case of the Moon. Mars clearly shows a solid surface with well-marked *permanent* features, by the observation of which it may be seen to rotate on its axis in a period only half an hour longer than our own day.

When we turn to Jupiter, the evidence is more

satisfactory, in spite of the much greater distance of that body. In every way there is the most marked contrast with Mars; in its gigantic size — its equatorial diameter being eleven times that of the earth—in its great polar flattening, but most of all in its physical condition. The most moderate telescope shows the familiar dusky *belts* of Jupiter, parallel with his equator. With a good instrument the picture is superb. The true cloud-like character of the bands then becomes evident, with their beautiful curling contours and intertwinings displayed as in a most delicately toned engraving. And on Jupiter the scene is always new. The broad outlines of the bands may last for months or years, but the more delicate cloud-tracery is in constant change. No feature on the surface of the whole planet is constant. We see merely a sea of clouds.

Now this constant and universal cloud-envelope of Jupiter is more remarkable than at first appears. True, our own skies are commonly enough filled with cloud, and were our atmosphere more dense we *might* never see the sun at all. But our clouds depend for their existence entirely on our proximity to the sun, whereby the surface of our planet is kept at a temperature which causes the watery vapours to rise. Jupiter is five times more remote from that source of heat, and must receive a correspondingly small supply. If, therefore, his condition resembled that of the Earth or Mars, any water on his surface ought to be eternally solid, and no cloud should ever dim his skies. Yet we rarely, if ever, see a rift in his cloudy shell. Again, all the winds and storms of our own atmosphere result from its disturbance by solar heat. Jupiter should be comparatively calm, and still most violent storms occur. Only one conclusion

can be drawn; the heat which is not supplied from without must come from within: Jupiter must be a hot planet. Certain other observations support this conclusion. The markings on the belts enable us to mark the rotation, and to make the noteworthy discovery that *all parts of the planet do not rotate with the same period*. The equatorial regions rotate in a shorter time than those nearer the poles. Clearly the atmosphere of Jupiter does not form a thin covering over a solid globe, or this would be impossible. The matter below the visible surface must be gaseous to a great depth, if not, indeed (as is not improbable) to the very centre. In further confirmation we have the remarkable fact that the *density* (i.e., the weight relatively to the size) of Jupiter is but one quarter of that of the earth. He is but little heavier than a similar-sized globe of water. The sun has almost exactly the same density. Either this means that Jupiter is made of extraordinarily light materials (which there are the very strongest reasons for doubting) or that the greater part, if not the whole, of the great globe is in a gaseous condition, which is almost tantamount to saying that it is at a high temperature.

The question naturally arises, if Jupiter is highly heated, whether he should not be self-luminous. That would obviously be a matter of *surface* temperature—of the visible surface. Direct observation can give no information as to the interior. Even regarding the surface, no definite answer can be given. Undoubtedly most of the light which reaches us from that surface is reflected sunlight. When one of the four larger satellites of Jupiter passes between the planet and the sun it casts a shadow on the surface, and that shadow looks intensely black.

Yet even this by no means proves that the surface is not luminous. The spots on the surface of the sun itself look as intensely black, and yet are certainly as bright as an electric arc. So little can the eye be trusted. On the other hand some observers have strenuously maintained that signs of inherent light are visible on Jupiter. However that may be, the evidence previously considered gives us much safer ground for judgment on the physical condition of the planet, and we may sum it up with little hesitation by saying that, as Mars shows us a condition intermediate between that of the earth and the moon, so Jupiter divides its resemblances between the earth and the sun.

Little more can be gained from a study of the other planets. Venus and Mercury, as far as we know them, are closely similar to the Earth and Mars respectively—essentially small, cold, heavy earth-like planets. Saturn, Uranus, and Neptune are light giant planets, probably like Jupiter, hot and sun-like.

To complete this brief survey of the Solar System we have to enquire what is known of the physical condition of the sun itself. The vast dimensions of that globe are difficult to realise, its diameter being about 108 times that of the earth, or about $3\frac{1}{2}$ times the distance which separates us from the moon. Though we have seen it is *relatively* only one quarter as heavy as our planet its *actual* weight is 330,000 times greater. The vastness of the heat and light it radiates must be in some measure evident to all. Though the problem of determining the real temperature of its surface is beset with very great difficulty, it has been solved with sufficient approximation for our purpose. The mere statement that it is probably

6000° or 8000° centigrade conveys little. It is double the temperature of the electric arc. It is a temperature at which the most refractory substances we know can exist only in a state of vapour. And that is the temperature of the surface only; the interior must be hotter still.

The state of things inferred from the evidence of temperature is confirmed by the telescope. The appearance of the solar surface has been well likened to a sheet of light grey cloth, almost hidden under a layer of freshly fallen snow. The "snow-flakes" are dazzlingly brilliant clouds, each some hundreds of miles across. It is doubtful if these are true clouds, consisting of liquid droplets; if they are, the droplets are of iron and the more refractory metals. Possibly they are purely gaseous. Whatever their precise nature, they are constantly under violent agitation. Mighty cyclones sweep them about with perfectly incredible velocities. From time to time they are completely cleared away from some area or sucked down towards the interior, when relatively cool gases from above fill the depression, and, cutting off much of the light from below, create a false impression that one is looking through a hole in the brilliant surface to a *dark* interior—a mistake to be carefully avoided. These "sun-spots" are among the most beautiful objects the telescope can show. When we have the brilliant disc of the sun hidden behind the moon during a total eclipse, we may witness another striking manifestation of the endless turmoil on his surface. Shot out in every direction are the so-called red-flames, in reality vast jets of glowing hydrogen and calcium vapour, tens or hundreds of thousands of miles in height. Fortunately, with the aid of the spectroscope, we are now able to cut out artificially

the brilliant light of the disc, which ordinarily overpowers the light from these "flames," and watch them actually thrown out from the surface, rising at times with the stupendous velocity of 300 miles *a second*. The most violent terrestrial hurricane is perfect calm by comparison.

In its rotation, the sun displays in a more marked degree the peculiarity we observed on Jupiter: the equatorial regions turn more quickly than the polar ones. While a point on the equator is carried completely round in twenty-five days, the period of revolution gradually increases to upwards of thirty days near the poles, again testifying that we have to do with a gaseous, not a solid globe. In the case of the Sun, the known temperature leaves no doubt that it is gaseous throughout. But perhaps the term is misleading. We have described it as a relatively light globe; but it is still somewhat heavier, bulk for bulk, than water. And that is merely its *average* density. While its superficial layers must be much lighter, its density must gradually increase towards the centre, the materials at any depth being compressed under the weight of all the overlying matter, so that the central portions may be denser, and far more rigid than steel. That the Sun as a whole is an intensely rigid body is amply shown by the absence of any perceptible polar flattening. Such conditions are scarcely consistent with our ordinary notions of a gas; but that is merely because we are only familiar with gases under low pressures. This general density and rigidity, nevertheless, does not prevent a very evident and effective circulation of the gases from the interior to the surface and back—an important fact to note, since it must keep the materials well mixed, if we may so phrase it.

We can learn from the Sun what will never be possible from the planets—the nature of the materials composing it. For the theory of that wonderful weapon of modern science, the spectroscope, we must reluctantly refer the reader to some work on astronomy or physics. Suffice it to say that every substance, when in a hot gaseous condition, and not under great pressure, shines with its own peculiar type of light: strikes, as it were, its own characteristic notes on the rainbow scale of colour. Every glowing solid, or highly compressed gas, on the contrary, gives out the entire range of colours, which blend to give the impression of *white* light: and from such light any ordinary gas will pick out and *absorb* the colours which it would show if shining itself, producing gaps, or dark lines, across the rainbow band. Precisely this condition we have in the sun; the light from the dense gases of his brilliant surface contains all the spectral colours. But as it leaves the surface it has to run the gauntlet through the *relatively* cool gases of his atmosphere. Each gas robs it of certain-coloured beams, so that when the light, as it reaches us, is analysed by the spectroscope, many thousands of dark lines are found across the rainbow-coloured band, representing the lost colours. The study of these lines results in a discovery of the most profound significance: of the eighty or so elements which the chemist has recognised as composing the multitude of substances he has been able to analyse, about two-thirds have thereby been found to be constituents of the Solar atmosphere. Copper, Zinc, Iron, Calcium and Magnesium are a few of the *gases* of this *relatively* cool atmosphere of the Sun. No more striking testimony could be found to the intense heat of that

body. But of far greater importance is the indication that the sun, however different in other respects, is composed of *essentially the same materials as the earth*. To anyone familiar with the difficulties of spectroscopic investigation, the wonder is not that we should not yet have found *all* the known terrestrial elements in the sun, but rather that we should have detected so many. The violent circulation of solar gases, already referred to, assures us that the composition of the low-lying layers of atmosphere in which the absorption of light chiefly occurs may be taken as fairly representative of that of the sun as a whole. And with that remark we must leave the many other wonders of this fascinating globe to the astronomer.

The various bodies of the Solar System are clearly very fundamentally related. Though we can never directly know the material of which the other planets are made, the example of the sun confirms what would be otherwise probable—that it would prove to be like that of the earth itself. And many likenesses pervade the system besides those we have already noted. All the planets revolve round the sun in the same direction, and in much the same plane. They all, together with the sun himself, rotate on their axes again in the same direction. We cannot but believe that the history of each must be intertwined with that of the others. The differences among them are differences of physical condition. The Sun is intensely hot, Jupiter still hot enough to be largely or wholly gaseous, the Earth cold and solid externally but with abundant evidence of *internal* heat, Mars certainly cold on its surface, while the Moon shows a rugged exterior, covered with the scars of volcanic fires long since extinct. As far as we can judge, it is now cold

to the core. The present state of the various bodies appears, therefore, to depend on size.

What relationship does the Solar System bear to the rest of the universe? So soon as the distance separating us from the Sun became known, it opened the way for an attack on the larger problem of the distance of the stars, and we are now in a position to state the remoteness of some of the nearer ones with tolerable certainty. But miles, or even millions of miles, are quite useless as units in which to express these depths of space. The movement of light provides the readiest means of comparison. A light-beam darts through space with a velocity of over eleven million miles per minute. A little more than eight minutes suffices for it to bridge the gap between us and the sun; about four hours and a quarter will take it to Neptune. But it must rush on through space month after month for $3\frac{1}{2}$ years before it reaches the nearest star, and it is likely to travel as far again before it strikes another. Such is space. The sun himself from such a depth must appear a star of small importance in the heavens.

Clearly the stars themselves must be sun-like bodies. Our telescopes, were they a thousand times more powerful, could never enable us to see them other than as mere points of light. Yet, knowing something of their distances, it requires no elaborate calculation to show that many a star must give out far more light than the sun himself. And while the telescope is rendered impotent by distance, the spectroscope can still analyse the light of the star, and learn something of its composition and physical condition. The result is to add enormously to the significance of what was learned regarding the sun. Turn where we may throughout the universe, the

same familiar substances make their presence known. Some may fail to appear — occasionally nearly all — but we look in vain for anything entirely novel. To be more precise, while some stars, like Capella, shine with a light which can scarcely be distinguished from that of the sun, others, like Sirius or Vega, have such vast atmospheres of hydrogen that the effects of other substances are almost masked. Others again seem to show the presence of certain chemical *compounds*, which would betoken a lower temperature, while we must add to the list those stars which no longer shine at all, and whose existence we should not be aware of but for their proximity to other stars whose movements they disturb. Some of these differences among the stars appear to be attributable directly to variations in size, others are certainly due to different temperatures.

Whether the stars, or any of them, have attendant planets we can, of course, never directly ascertain. Yet the study of their probable history renders it practically certain that they have. Besides the stars, the telescope reveals in the sky large numbers of faint cloud-like bodies—the *nebulæ*. They appear of every size from masses which, despite their unfathomable remoteness, cover areas of sky larger than the moon (invisible to the naked eye because too faint) down to mere hazy specks only visible with the best telescopes. The smallest of them must be larger than the whole Solar System. The larger ones must occupy the most inconceivable regions of space; yet so flimsy are they that the faintest stars are visible through all but their densest central portions. The smaller are usually more compact. They pass, indeed, insensibly into nebulous stars. What, then, are these airy bodies, and what are their

relations to the stars? Tested again by the quality of their light, some of them show, like the stars, the presence of many of our familiar elements in a gaseous condition. Others, however, show nothing but two or three substances which are gaseous at ordinary temperature—notably hydrogen. And these nebulæ send us *no other* light than that produced by the glowing of these few gases. But further information may be gleaned from certain bodies which partake in some degree of the nature of nebulæ and which we are able to examine at much closer quarters, namely, the comets which from time to time appear. Some of these are regular members of the Solar System, others visit us from remote regions of space. They occasionally pass very close to one of the planets, or even collide. Then there is a disaster—to the comet. The space within the solar system is literally strewn with their wreckage, and the Earth, as it dashes through, attracts the scattered fragments to itself in millions. When a fragment falls, the friction created by its headlong rush through our atmosphere raises it to incandescence, or drives it off in vapour. We witness the familiar spectacle of a shooting-star. Of all the thousands of these which fall on the earth every day, one rarely escapes complete dissolution in the air. It does occasionally happen, however, and our museums contain not a few of these justly treasured meteorites—the only samples of the outer worlds we can ever take in our hands to examine.

The careful examination of many hundreds of these meteorites has not resulted in the recognition of a single substance with which we were not already familiar. And there is every reason to believe that a comet is nothing more or less than a swarm of

myriads of these bodies—the dust of space. The comet glows because the meteorites clash together as the swarm rushes on its course, some being thereby made hot, others possibly vapourised, though the vast majority are cold and black. What is true of the comet, is in all probability true of the nebula. There is every reason to believe that it is likewise an immense scattered meteoric swarm. When it is very widely scattered, collisions among the particles are few and the general temperature consequently low. Only a few gases therefore shine out. But it is readily demonstrated on purely mathematical principles that such a vast swarm will gradually contract, in consequence of the mutual attraction of all the particles. As it becomes more closely packed, collisions will be more frequent, and the general temperature will rise. The light given out will gradually become more like that of a star until the swarm becomes so compacted and the temperature so high that no substance can longer remain solid, but the whole becomes a globe of dense intensely hot gas. It has ceased to be a nebula and become a star. Unable to contract further, its accumulated heat will be gradually radiated away, the successive stages of cooling giving rise to some of the types of stars already referred to. Cooling will continue until it rolls through space a dead black globe, unless, as is very probable, some passing star comes so close as to cause its disruption and a return to its primitive meteoric condition, when the whole story must begin afresh.

We have assumed our swarm to contract absolutely uniformly to the centre. But that can rarely happen. Unless it is uniformly distributed to begin with, minor centres of condensation must be set up,

and if, as is usually the case, the whole nebula has a rotatory motion, these minor masses will never join the central sun, but will continue to revolve round it, while each contracts and collects up the meteorites in its neighbourhood as it gradually resolves itself into a *planet*. Such, in its broad outlines, we believe to have been the origin of the Earth. Thus in the thousands of beautiful spiral nebulæ in the heavens we may watch the evolution of new Solar systems. In the central condensations we see the future suns; in the knots on the spiral nebulous folds which surround them, the embryos of their planets. And in the stars and the greater planets we may witness something of the stages of development through which the Earth itself may have passed. Precisely how far it has passed through them it will be the business of the future geologists to discover.

CHAPTER II

VOLCANOES AND EARTHQUAKES

IN the preceding chapter we have considered the Earth in relation to the other worlds of space, and gathered from them some suggestions as to its early history. It now becomes our duty to examine a little more closely the Earth itself, and to see what manner of world it is on which we dwell. Our direct acquaintance with it is, after all, very feeble. By united effort we have explored most of its surface, and here and there have crept a mile or so towards the interior. As we shall find in the sequel, we may even examine materials which have been perhaps ten miles deep. But what of that? The skin of an apple bears a larger proportion to the whole than a ten-mile layer to the earth. Two questions we chiefly want answered: Is the material which forms the visible surface of the globe a fair sample of the whole? And what is the physical condition of the great interior mass?

Indirect evidence alone can furnish us the answer. Something may be learned from the weight of the globe, and something, too, from its behaviour in relation to its fellow-worlds; but, most directly, the evidence of volcanoes and earthquakes, with their allied phenomena, comes to our aid.

The problem of weighing the earth is a highly interesting and, in theory, a very simple one. Everyone knows that the weight of a body is merely the

force with which it is attracted to some other body—in ordinary cases, to the Earth. The strength of the attraction—in other words, the weight—depends on three things: the amount of matter in the body, the amount in the earth, and the distance between them (or, rather, between their centres). In ordinary instances, it is only the first of these which is varied. Hence, if we find that one body is attracted with twice as much force as another (i.e., if it is twice as heavy) we are justified in concluding that the former contains twice as much matter as the latter. But this would no longer be true if we varied the other factors. For example, if we could transport a pound of sugar to the surface of the Sun, we should find that it there weighed nearly two stones—but there would be no more sugar. The increase of weight would be due to the enormous mass of the Sun. If these simple facts are comprehended, there is no difficulty in understanding how the earth itself may be weighed. Suppose we take a large ball of lead, weighing 1 cwt, and place near it a small ball of some kind. Here we have, in miniature, a model of the earth and a body near its surface. The difference is one of scale alone. The small ball is attracted towards the large one (more accurately, of course, they attract each other). The attraction is all but infinitesimal, yet with sufficiently delicate apparatus it is measurable. We can measure, that is, the *weight* of the small ball, due to the attraction of the large one. But we also know its weight (its ordinary weight) due to the attraction of the Earth. The difference between these two weights is clearly due to the difference between the amount of matter in the lead ball, in the one case, and the Earth in the other, allowing for the difference in their respective

distances from the smaller ball, also. Hence, knowing the amount of matter in the lead ball, we can calculate by proportion the amount in the earth, or, in more popular language, the weight of the earth. Various methods have been used for the solution of this fascinating and important problem, but the fundamental principle is the same in all—the comparison of the forces with which some small body is attracted by the earth, on the one hand, and some other body whose weight is known on the other.

The statement of the weight of the earth in tons would be, of course, utterly meaningless. What is significant is its *relative* weight, which may best be stated as almost exactly $5\frac{1}{2}$ times that of an equal-sized globe of water, or more than two-thirds that of one of solid iron. As a whole, therefore, it is a distinctly heavy globe. This knowledge enables us to answer, in some degree, the first of the questions proposed; for, as everyone knows, the ordinary rocks accessible to us are comparatively light substances. They vary, naturally, but the great majority of common rocks are relatively from $2\frac{1}{2}$ to 3 times heavier than water; and we may say with perfect confidence that the average density of the outer crust of the earth is about $2\frac{3}{4}$ times that of water, or almost exactly one half that of the entire globe. Whatever the reason, it is clear that the lighter materials preponderate on the surface, and the heavier inside. For the present, we will be content with noting the fact.

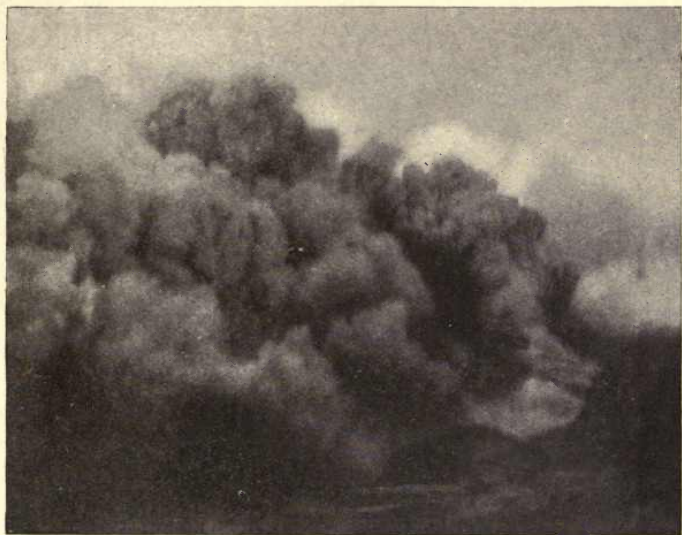
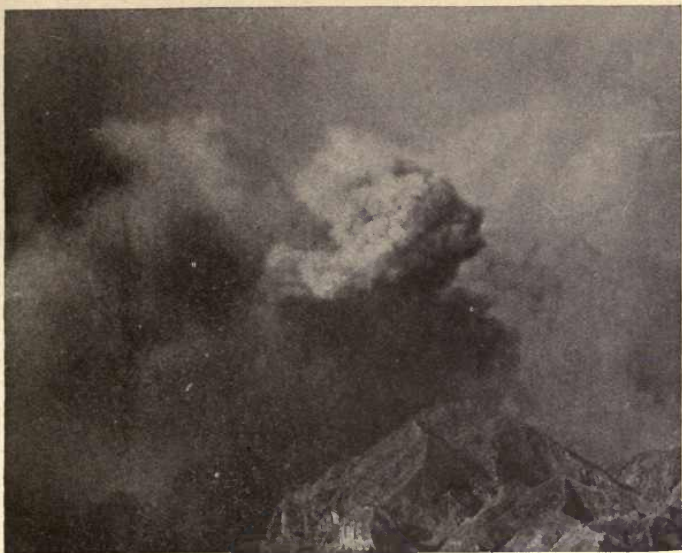
Volcanoes form by far the most impressive testimony to a heated condition of the interior. But we must note in the first place a much more general indication of the same fact. In these days of deep mining, everyone is familiar with the fact that the

rocks become hotter as we descend below the surface, this being one of the most serious obstacles to the further increase in the depth of our coal-mines. Every deep boring or sinking which has been made, in every part of the world, has told the same story of a more or less uniform rise of temperature with increase of depth. The rate of increase, or temperature gradient, as it is called, varies considerably in different places, so that even a fair average cannot easily be obtained. The most generally accepted figure is about 1° Farenheit for every 60 feet of descent. From our present standpoint the exact figure is of no moment. Consider what it means. The figure given is equal to a rise of 88 degrees to the mile! If this continues, everything at a depth of a few miles must be red-hot; at twenty miles, the temperature will be above the melting point of the most refractory substances known! Here, indeed, is an astounding conclusion. Can we consider ourselves justified in extending the purport of our observations so far?

Corroborative evidence is forthcoming in the hot springs found in every part of the world, and especially in those remarkable springs—the Geysers—from which super-heated water is belched forth; but most of all the volcanoes support the conclusion.

The crude notions once prevalent concerning volcanoes have been largely cleared away, yet few natural phenomena, perhaps, are more vaguely apprehended. Some definite conception may probably best be attained by the briefest history of an actual eruption. Few natural disasters in modern times have compelled more sympathetic attention than the devastation of Martinique in 1902. The West Indies are encompassed by a great volcanic

zone, but the island of Martinique showed no symptom of volcanic activity for more than two hundred years after its discovery. First in 1792, violent earthquakes disturbed its unbroken peace, and a slight eruption took place on Mt. Pelé. Quiet was soon regained, and lasted until 1851, during the summer of which year a sulphurous odour was observed to hang round the mountain. On the 5th of August violent explosions were heard, and a covering of dust was observed over the summit on the following day. The whole disturbance resulted from explosions of gas and steam. At intervals until the end of the year these outbreaks were continued, after which quiescence reigned again for nearly another half-century. Already in 1889, however, the portents of coming disaster began to appear. Little clouds of steam began to curl up from the mountain, and the sulphurous gases re-appeared. In 1900 the emissions increased. Earthquakes became frequent. By March, 1902, the odour of the gases had reached St. Pierre. By the 22nd of April the earthquakes were so severe as to break the submarine cable to Guadeloupe. Two days later the column of vapour and dust from the explosions rose two thousand feet above the mountain, and the next day began to fall in the surrounding villages. Explosion followed explosion every two or three minutes. A comparative lull on the 26th was but the calm before the next, and in one respect most frightful storm. Until the 8th of May things grew steadily worse. Earthquakes became most frightful and almost continuous. Ashes began to fall over the whole island. The pall over the mountain grew in size and denseness, putting all the region below it in blackest darkness.



ERUPTION OF MT. PELEÈ, MARTINIQUE, 1902.

Reproduced by the kind permission of Dr. Tempest Anderson.

Upper photograph slightly modified by retouching.

The streams burst their banks from the torrents which fell. Lightning and thunder in the cloud mingled with the roar of explosion and earthquake. First the cable to Dominique, then that to St. Lucie, broke under the strain of repeated shocks. On the fatal 8th, the great cloud rose higher than ever before, every violence was at its worst, when the huge curling pillar rolled down to the sea, and in a few minutes blotted out St. Pierre with its twenty-eight thousand souls; fire, started by the red-hot blocks of lava, destroying anything which was not crushed under the weight of falling stone and dust. Blocks of stone a hundred cubic yards in size fell mixed with smaller stones and the finest dust. From the human standpoint the eruption had done its worst; but it yet waxed more terrible. The 20th and 26th of May and the 9th of June were each marked by accessions of violence equal to that of the 8th, while the climax was not reached until the 30th of August, when all previous efforts were surpassed by the production of a cloud several miles in height, which buried half the island in dust and took toll of another thousand lives. When it rolled away the island looked like a country buried in snow.

In the preceding description, reference to molten lava has been purposely omitted, because it plays much too large a part in the popular idea of an eruption. Lava streams were ejected, the first being seen two days before the destruction of St. Pierre, or about the twelfth day of the outbreak. But in this, as in most eruptions of the more violent type, the great mass of the ejection consisted of *solid* material blown out and shattered by the explosions, much of it reduced to the most impalpable powder.

This eruption was remarkably similar to the classical outburst of Vesuvius in the year 79, of which we have so circumstantial an account in the description given by the younger Pliny to Tacitus. All the essential features were exactly repeated. One sentence of the narrative deserves quotation. Speaking of the scene presented after the three days of perfect darkness we are told: "Every object which presented itself to our eyes—which were extremely weakened—seemed changed, being covered over with white ashes, as with a deep snow." Everyone knows that the same story was repeated again in the recent great eruption of 1906.

One more great outburst may be referred to by way of giving a more complete idea of the magnitude which volcanic forces may attain. The small island of Krakatoa, in the strait between Java and Sumatra, showed no sign of volcanic nature until 1883. In May of that year a comparatively slight eruption took place, but only in the following August was there any indication that a violent disturbance was about to occur. Then in two days (the 26th and 27th), *two-thirds of the whole island was blown away*, the original island being six miles by three. New islands were formed in the neighbourhood, and the map of the region rendered completely useless. The cloud of steam and ashes rose to a height of 17 miles, and darkness extended for 150 miles from the volcano. The fine ash was subsequently carried by the winds to every part of the earth. So fine was some of the powder that it was estimated that about twenty-thousand particles would go to a single grain. Though we may be thankful indeed that the event occurred in a sparsely

populated portion of the globe, no less than 36,380 lives were lost. The sound of the explosions was heard so far away as Rodriguez, distant 2,500 miles, while the great sea-waves caused by the accompanying earthquakes devastated many hundreds of square miles of country, and in one case carried a man-of-war three miles inland, and left it stranded thirty feet above the sea. The foregoing facts are

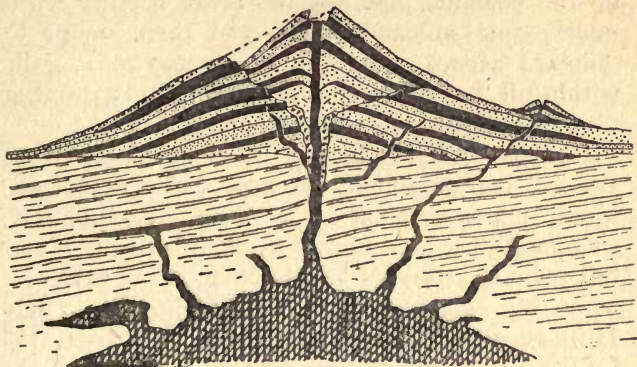


FIG. 1.—IDEAL SECTION OF A VOLCANO.

Lava black; ash dotted. The original cone has been partially destroyed, and a new one constructed within. On the right, a small "parasitic" cone has been formed. Dykes of lava are seen penetrating the various rocks.

indeed a mighty tribute to the forces within the earth. And they are no mere fancy of over-excited narrators, but the result of evidence collected by a special commission appointed by our Royal Society to investigate the circumstances of the eruption.

Very different is the story of such a volcano as Stromboli, whose constancy has well deserved its popular appellation—the "lighthouse of the Mediterranean." Year in and year out the puffs of steam lazily curl up from the crater, the molten lava gently

heaves and falls within, carrying with it the slaggy floor, and rarely rising high enough to cause a little to well over the side. Violence is almost unknown.

It needs little reflection to see the meaning of this difference of behaviour. In the case of Stromboli, and others like it, the volcanic forces—the steam and other gases—are continually escaping, and the energy is thereby slowly dissipated. But only seal up the volcanic pipe, let the lavas solidify within, make your volcano sleep, and then, under this outward aspect of repose, the forces must gather within till they burst all their bonds, and a great and disastrous eruption is the result.

Equally evident should be the reason why a volcano has commonly the aspect of a mountain of more or less comical form. Any misconception of this point may be removed by the history of a small hill near the Bay of Baiæ, north of Vesuvius. It bears the significant name of Monte Nuovo (New Hill) because its existence dates only from 1538. Of the rise of this hill we possess the account of an eye-witness. Before the year mentioned the site was a low-lying tract of ground. Volcanic activity, as usual, was announced by earthquakes for two years before the event. On the 29th of September, 1538, twenty shocks occurred in the one day. The following night a slight sinking of the ground took place, followed by gushing out of water, first cold, then hot. Later, flames were seen, and then the ground was torn open, and an eruption of ashes began, which in two days built up the present hill, 440 feet in height. By the end of a week the eruption ceased, and it has not since been renewed. Here, in miniature, we have the history of all volcanoes, their cones being built up of the ashes

and lava shot out from the vent, whether they be small hills like Monte Nuovo, or vast mountains like Etna. Yet the same force which builds up the cone not infrequently leads to its destruction. Many volcanoes are mere wrecks of their former selves. The old Vesuvius—Monte Somma—was largely blown away by the historic eruption of A.D. 79, the present cone being a new one, while in such a volcano as the well-known Kilauea we have a mere low wall left round a great lake of lava, practically the entire cone having been destroyed.

The realisation of the true nature of the cone prepares one for the appreciation of a fact, the significance of which may otherwise be lost—the circumstance, namely, that volcanoes are usually to be found along the great mountain ranges of the world, and like them, therefore, chiefly by the borders of the great oceans. This association of volcanoes with mountains is readily understood, for, as we shall see in the sequel, the mountain chains are the great lines of weakness of the earth's crust, along which all the pent-up energies of the interior exhibit their most profound effects. But why they should be found bordering the oceans is a problem much more profound and much less readily solved. As regards the volcanoes, at any rate, the association has given rise to a hypothesis, which, true or not, serves to emphasise one of the most noteworthy of volcanic phenomena. No fact stands out more prominently in the accounts which have been given above than the important rôle played by *steam* in every eruption. It is the motive power of the entire action. The explosions which hurl solid rock and molten lava alike into the air are almost entirely explosions of steam. The earthquakes

themselves, which are so inseparable from all violent eruptions, are not improbably due in large measure to more deep-seated explosions of the same character. The actual amount of water given off in the form of vapour from a great volcano, even in a brief space of time, baffles imagination. It is not without reason, therefore, that the view has long been put forward that the whole existence of volcanoes is due to water which has percolated down from the oceans through fissures to the heated rock below, the fluidity of which has been increased by its solvent powers, till the mobile mass has yielded under the pressure of the overlying rock and sought its way in turn through some fissure to the surface. The one point in dispute is the ultimate source of the water. But whether it is derived, as described above, from the oceans, or, as others suppose, it has been imprisoned in the rocks since the earth became a planet, its vital importance is undoubted.

Nevertheless, the water is, of course, for the most part, merely the agent through which the real cause of the whole phenomenon is made manifest. The internal heat of the earth is the real source of energy which gives the water its explosive power, which shatters the rocks, and hurls millions of tons of them miles through the air. Looked at in this light, the vast clouds of steam and solid fragments, the explosions and the earthquakes, are no less eloquent of the vast stores of internal heat than the molten rocks themselves. And though we have referred to certain limitations in the distribution of existing volcanoes, they are still very widely spread over the face of the globe. The entire west coast of the Americas is one long line of them from Alaska

to Cape Horn. Across the Pacific, another line stretches from the north-east of Asia through Japan, the East Indies, and New Zealand, on to the South Polar Continent. And a third great belt runs across the whole of southern Europe and Asia, practically joining the other two, to omit all reference to scattered volcanoes. These are merely the volcanoes of the present day; were we to include all those of past geological ages, scarcely a spot on the globe would be free. Little wonder, then, that the early geologists imagined that the whole earth, except quite a few miles down from the surface, must be one molten mass. To them, the "crust" of the earth was a perfectly literal crust.

What are we to say of these ideas to-day? The evidence of internal heat is not one whit less convincing than formerly. Indeed, the more advanced state of physical science probably justifies us in placing more reliance on the general indications than was proper for the older geologists. There seems to be no escape from the conclusion indicated at the outset, that at a depth of twenty or thirty miles the temperature must be above the melting point not merely of the ordinary rocks but of every substance with which we are acquainted. Below the volcanoes, as we shall see later, reservoirs of molten rock exist at much smaller depths. Is the interior, then, liquid? Perhaps we ought rather to ask, is it gaseous? For most substances remain in the liquid condition through a comparatively small range of temperature; after they are liquified, they are soon vapourised.

Until recently, we have been under the necessity of appealing again to the astronomer for evidence on this question. In principle, the method by which

Sir George Darwin has attacked the problem is readily understood. Everyone knows that the tides are caused by the attraction of the Moon. Owing to that body being comparatively close to us (its average distance is rather less than 60 times the earth's own diameter) the attraction is appreciably greater on that side of the earth which is, for the moment, nearer to the moon, than on the remoter side. As a result of this unequal attraction, the moon constantly tends to pull the earth out of shape; and in the case of the oceans it succeeds, tides being the result. The solid globe does not appreciably yield, and by mathematical analysis it is possible to calculate what its rigidity as a whole must be to withstand the enormous strain which the moon puts upon it. Darwin concludes that it must be more rigid than a sphere of steel. Everyone, at least, will readily understand that if the interior were liquid in the sense once supposed, tides like those of the ocean would be created in this fluid mass, which the feeble solid crust would be utterly unable to withstand. Without paying attention to the other astronomical methods of approaching the problem, let us turn to a more strictly geological field which offers great promise.

Earthquakes, after the recent disasters of San Francisco and Messina, are only too familiar in their general manifestations. The heaving of the ground, which in the most severe shocks may even cause the earth to gape open with the strain, the overthrowing of pillars, chimneys, and even houses, are well-known phenomena. After a great earthquake, various permanent changes are usually observable in the district affected. Streets, railway lines, and similar features which were previously

straight have become more or less crooked. Fields which were rectangular have their sides no longer square. The ground in some areas may be permanently raised, and in others depressed. In some instances, as in the great earthquake which affected the Mino-Owari districts of Japan in 1891, a great line of fracture may be developed for miles across the country, along which it may be raised on one side or depressed on the other to the extent of even twenty or thirty feet. *Lateral* displacement of the ground of still greater magnitude occurred along the line of fracture in the San Francisco earthquake. These displacements are, indeed, the very essence of the earthquakes. There is little doubt that the majority of shocks are due to just such sudden slippings of the earth's crust along some line of fracture. We shall see later that these lines of fracture and movement are among the commonest of geological phenomena in every part of the world; and not one can have arisen without giving rise to an earthquake. Most, indeed, can only have resulted from a long succession of slips, each giving rise to a more or less severe shock. The difficult question of the ultimate cause of these sudden snappings and slidings must be postponed awhile. Meantime, let us fix our attention on the nature of the shock itself. Could we free ourselves from the ground during an earthquake and attentively watch any point on it, we should see it moving up and down, backwards and forwards, side to side, in a most complicated dance. But it is just the misfortune that we *cannot* free ourselves which makes reliable observation difficult, and greatly exaggerated statements the general rule. However, it needs no refinement of observation to ascertain

the essential fact that the earthquake proper is a *vibration* of the ground. As an iron bar struck on one end with a hammer is set into vibration which travels in rapid waves along the bar, so the earth, shaken by a sudden snap, vibrates in like manner, and the vibrations spread out in waves in every direction from the place of the shock. The waves travel rapidly. A minute suffices for them to cover several hundred miles; but as they spread out they are correspondingly weakened, so that they soon cease to affect our senses. The study of these waves is the essential feature of the science of Seismology, a science yet in its earliest infancy, but one which is already shedding light on the state of the interior of our globe, and which seems destined in the near future to place our knowledge of that subject on a surer footing than it has ever been before. The first requisite of the study is an accurate record of the movements which any point of the ground undergoes during a shock. Clearly this can only be obtained by referring the movements to some body which is at rest, and here is the problem: how to obtain a "steady point"? No body, of course, can be completely detached from the ground; yet we may have it detached in certain respects. Take an ordinary pendulum for example. If the support to which it is attached is moved *up and down*, the whole pendulum must be carried with it; but if the support is moved *sideways*, the weight of the pendulum will tend to remain at rest where it was. If now the support remains in its new position the pendulum will begin to swing. If, on the other hand, it moves quickly back to its old place, little disturbance of the weight may occur. Unfortunately, no matter how quickly the move-

ments are performed, some swinging will occur; and, moreover, the actual movements in an earthquake are comparatively slow. By a variety of mechanical contrivances, however, this tendency to swing may be more or less completely counter-balanced, and so a modified pendulum may be used to record the horizontal movements of the ground during an earthquake, a pointer attached to the pendulum writing on a recording roll of paper which moves with the ground. A similar pendulum may be constructed which swings vertically instead of horizontally, and used to obtain a tracing of the vertical movements.

The first fact we learn from such instruments—seismographas, as they are called—is that the actual movements in an ordinary earthquake are small. Any shock in which the ground actually rises and falls more than an inch is a severe one. In the great majority, the movement is much smaller. We are, further, able to confirm another important and significant observation. An earthquake, in the region where the shock originates, is not heralded by any previous trembling of the ground. The full force of the shock falls at once, without warning. Now this is not the case when a shock is felt at a considerable distance—say one or two thousand miles—from the point of its origin. In such a case the instrument shows a gentle trembling for some minutes before, quite suddenly, the main earth-waves arrive. At such a distance, of course, even the principal shock is scarcely, if at all, perceptible without the instrument. Now what is the meaning of these “preliminary tremors”? Clearly they are vibrations which in some way have raced the main waves. Those latter waves, we know, travel over

the *surface* of the earth, much as common ocean waves travel over the sea. Can it be that the preliminary tremors are waves which have taken a short cut *through* the globe? Two observations suffice to settle this point. Firstly, the further we go from the centre of disturbance, the longer is the interval by which the main shock lags behind the preliminary tremors; and clearly, the further we go, the greater would be the advantage gained by waves cutting *through* the earth. Secondly, when we *time* the waves accurately, we find that the intervals taken by the main waves to pass from place to place are proportional to the distances measured over the surface, while the time taken by the preliminary tremors to reach any point is nearly proportional to its distance from the point of origin measured *through* the earth.

These preliminary tremors now possess a most profound interest. They reach us after having passed through the innermost recesses of the globe, and we may be sure that, can we but interpret it aright, they bring with them a record of their adventures within. One, and that the most important, point is readily gathered. The speed with which a wave travels through a body depends mainly on the *rigidity* of that body: the more rigid, the greater the speed. Clearly then, if the interior of the globe be liquid, or diminished in rigidity by the intense heat towards the centre, those waves which have traversed the deeper regions will be retarded. What do we find? That the preliminary tremors which have passed most deeply through the globe, to emerge near the antipodes of the point from which they started, have travelled a little faster than those whose paths have not been so

deep. Here, then, we have a striking confirmation of what Darwin has told us from his studies of the tides. The interior of the globe is at least as rigid as the crust, and possibly more so.

What are we to make of the seeming contradiction? On the one hand we have the clearest evidence of high temperatures at quite small depths, and the strong probability of truly sun-like temperatures towards the centre. On the other we have unimpeachable testimony to the fact that the globe is a most rigid body to the core. If you consult a text-book of geology for the answer, you are likely to find the statement that the interior is extremely hot, but is kept in the solid condition by the enormous pressure of the overlying portions. It is a familiar fact that when a body is kept under great pressure its melting point and boiling point are usually raised. Unfortunately the physicist is likely to point out that there is a limit to this process, that there is a certain definite temperature for each substance—its “critical temperature”—above which it will pass into the gaseous state no matter how great the pressure to which it is subjected; and he may add that there is good reason to believe that the temperature within the earth may be above the critical points of most of the substances composing it.

Yet, in face of what we have seen, can we believe the interior to be gaseous? We must leave the responsibility for an answer with the physicist. Of this we may feel certain, that before the heat may compel the rocks to pass into a gaseous condition, the pressure will be so enormous that a gas under it will have no resemblance to anything of which we have experimental knowledge. The truth

is that we have to do with a state of things altogether foreign to our experience, and we cannot postulate what the properties of matter may be under such conditions. Perchance the tremor of the earthquake may yet enable us to learn.

CHAPTER III

THE SOLID ROCKS

It is now time to interrogate the rocks around us. Some of them readily yield their story; others divulge their secrets only after patient investigation. On the one hand, let us consider the rocks which are so admirably displayed along the coast from Whitby to Flamborough. The most casual glance at those magnificent cliffs suffices to show that the rocks are arranged in *layers*, sheet laid over sheet, through thousands of feet of rock; now a layer of sandstone, now of shale, now of clay, and now of limestone. They are *stratified* rocks (compare Fig. 2). We take a piece of the sandstone and scrutinise it more closely. The grains of which it is made are not to be distinguished from the sand-grains on the beach; each is rounded and smoothed, as those are being made in the dash of the waves. We crush the stone, and sand it becomes. Or we pick a fragment of shale or clay. While dry it is hard and compact; but only place it in water and it crumbles to mud. We take another block, break it open, and find within the beautiful form of a coiled shell with all its delicate ornament; but not the form merely—it is a shell, too real to

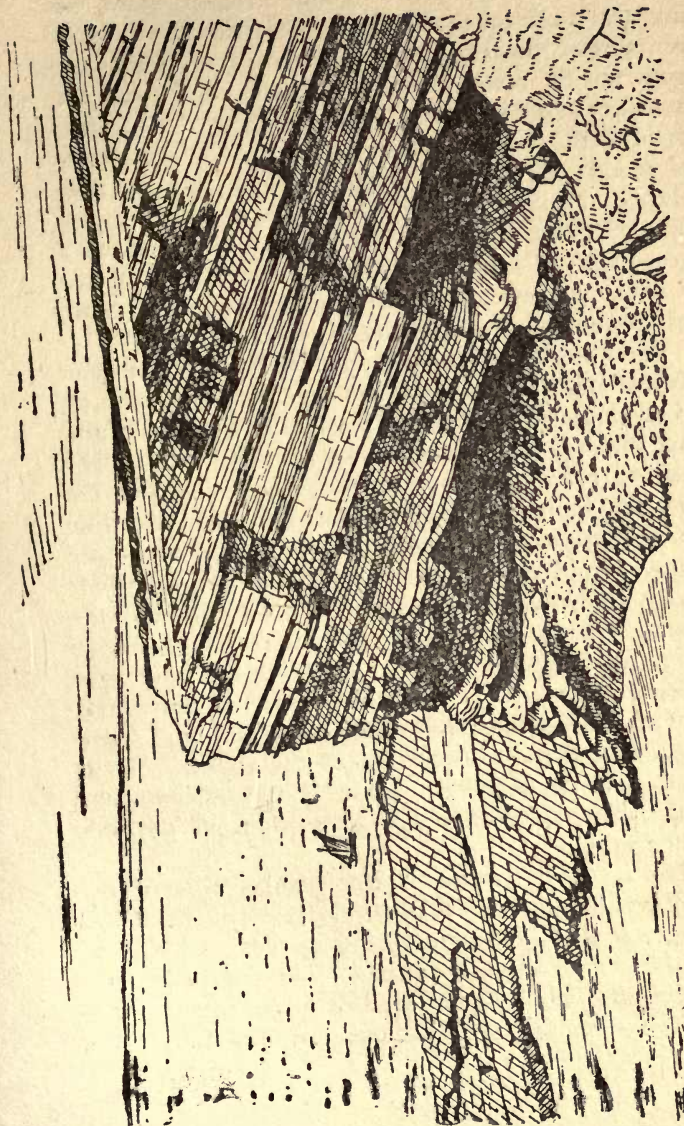


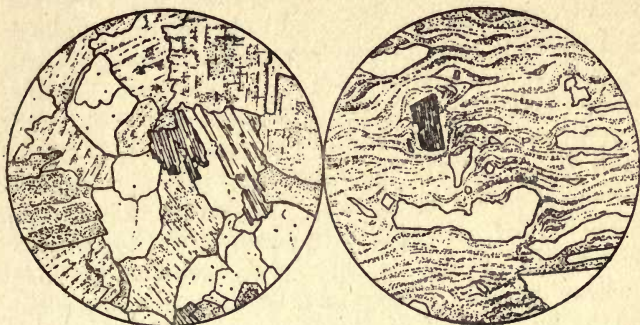
FIG. 2.—AUGHROS HEAD, CO. SLIGO. Inclined strata of Carboniferous Limestone. The sketch also illustrates the undercutting of the cliff by the sea (see Chapter V.).

deceive (see Plate IV.). Fully aroused now, we find the rocks on every hand filled with these fossil remains of vanished life; shells of every form and size, corals, sea-urchins, fish scales, and even the bones of some animal. The next layer of rock may yield us the most beautiful fern fronds, or fragments of wood; at least the form of them, for the substance is changed. Or we chance on a spot at the foot of the cliff where the storm has dislodged a great slab of sandstone, and see the surface of the bed below marked with ripples as perfect as those left yonder on the sands by the retreating tide.

What does it all mean? If the facts around you do not proclaim the answer loud enough, move on to the Humber, and there watch the sandbanks and mudbanks growing, layer upon layer, out of the burden brought down by the rivers, burying the cast-off shells left upon them, and only awaiting consolidation to become the new rocks of future ages. Thus readily the stratified rocks tell their story, and show that where is now dry land the ocean rolled, and buried on its sandy bed the remains of creatures whose very kind has long since passed away. They are built up out of the wreckage of pre-existing lands—for sand and mud result only from the disintegration of the rocks. What then, are the primitive rocks, if, indeed, any may still exist which have not been through nature's grinding mill?

Let us turn to one of the granite hills of the Scottish highlands. Here is no trace of stratification, no alternation of bed with bed, no sign of fossils. The whole mountain is one uniform mass of granite, whose even texture is reflected in the smooth, monotonous grandeur of the hill. We

come closer and take a sample of the rock. No rounded grains betoken the rolling of the sea. Instead we catch the glitter of crystals whose polished faces have never yet been dimmed. Still closer scrutiny reveals the fact that the whole rock is crystalline. Here a bright metallic-looking flake of olive-brown mica is embedded in a fleshy-pink crystal of felspar. There an irregular space is filled with clear glassy quartz. Do you marvel at the



A.

FIG. 3.

B.

A—Thin slice of Granite from Dalbeattie, Scotland, magnified 12 diameters. The clear crystals are quartz, the cloudy ones felspar, those with numerous parallel cracks mica.

B—Thin slice of Rhyolite from Elfdalen, Sweden, magnified 12 diameters. The glassy ground-mass shows "flow-structure," and contains multitudes of minute "crystallites" which cause the cloudy appearance. The large crystals are much broken and corroded.

wonderful accuracy and intricacy with which the crystal grains are fitted together and interlocked? You may search the rock with lens and microscope; not the smallest space is left unfilled. The truth proclaims itself irresistibly that the minerals have *grown* together (see Fig. 3A). How can such a structure have been attained? We can conceive of only

two possible answers. Either the minerals must have crystallized out from some solution, or the whole rock may have been in a molten condition and have crystallized as it slowly cooled and solidified.

It is indeed not easy to imagine how such minerals as felspar, quartz, and mica could be dissolved in quantities so vast. Water, we know, has wonderful powers of solution. Even such minerals as these are dissolved, though in excessively minute proportions; and in the early days of geology her followers were sometimes less disposed to bridle the imagination with the sordid considerations of mere physical facts than this matter-of-fact age demands. Moreover, there was ample justification for the belief that the primitive oceans of the young earth might have been highly heated, and thereby greatly enhanced in solvent power. So arose, during the latter half of the eighteenth century, the hypothesis that rocks of the granitic class represented the earliest deposits from the primæval oceans, a view taught by Werner, of Freyberg, and spread by his pupils over the length and breadth of Europe. When the waters cooled, they were no longer able to hold these minerals in solution, and their formation ceased, giving place to the deposits of mechanical sediment which form the rocks of later ages. But at the same period minds were not wanting more willing to abide by ascertained physical facts, and to observe more closely the phenomena of the rocks. Our countryman, Hutton, steadily opposed the Wernerian teaching, as being supported neither by chemical and physical considerations, nor by the facts observable in the field. A controversy was carried on for many years with more than academic ardour between the "Neptunists," as the followers

of Werner were dubbed, and the "Plutonists" who, with Hutton, believed the granitic rocks to have resulted from the slow cooling of molten material in deep reservoirs below the surface—in the regions which mythology had consecrated to Pluto. Hutton, with keen insight, perceived a crucial test. If Werner were right, then the stratified rocks must lie evenly upon those of the granitic class; no confusion could occur at the line of junction. On the contrary, the Plutonist might expect to find his molten granite injected into all the cracks and crevices of the overlying stratified rocks. It was a momentous journey when Hutton set out to observe the edge of the granite mass in Glen Tilt, and we may well credit the story that his exultation was so great on seeing the veins and strings of granite penetrating into the adjacent rocks that his guides believed he had discovered gold. For him, the great controversy was ended, and he had won.

The reader may be disposed to think that the controversy was unnecessary—to say that volcanoes clearly show the existence of reservoirs of molten rock below the surface, and thereby settle the question at once. But not so; far from it. The lavas were one of the surest strongholds of the Neptunists. And if the reader will take a piece of lava from Vesuvius in one hand, and a fragment of granite in the other, the force of the argument will appear. Indeed, could any two rocks be more unlike? On a casual inspection, assuredly not. The latter is a pale grey or pink glittering crystalline rock, the former a nearly black dull stony mass. True, a closer inspection of most lavas shows a good sprinkling of well-developed crystals scattered through them, but, nevertheless, the ground-mass of

the rock remains, to the eye, compact and stony. Hutton's penetrating sagacity enabled him to foresee the explanation of this striking difference, but much patient investigation was needed before his views could be clearly demonstrated.

In order to attack the difficulties one at a time, let us reject the Vesuvian lava for the moment, and take a lighter coloured specimen from one of the volcanoes of the Lipari Islands. Here again we see the stony-ground mass with embedded crystals, among which we recognise colourless quartz and felspar and blackish glistening micas. To make further progress we must appeal to the microscope, and examine with it a thin transparent slice of the rock. The picture presented as we look down the tube reminds us strongly of the surface of some sluggish stream covered with a light brown scum, which winds in curling eddies round floating logs and weeds (see Fig. 3B). The "logs" are the crystals we have already seen, the "scum" is the ground-mass of the rock. But the eddies are no make-believe; they are frozen solid, but they carry us back irresistibly to the day when, in a fiery stream, the rock flowed down the mountain-side. To disclose the secret of the ground-mass we must use a high magnifying power. We now find that this owes its turbid appearance to a host of minute crystals, some just recognisable as quartz or felspar, others mere rudiments of crystals distinguishable only as minute rods or beads; and all are embedded in a structureless, glassy matrix, which is, indeed, a natural glass.

Experience will soon teach us that different lavas vary considerably in character. The large crystals are an almost constant feature; but in the stony

groundwork we discover the most wonderful variety. In some cases we find nothing but pure glass, or glass containing only swarms of the little rod-like and bead-like bodies; in others, the whole is minutely crystalline. Nay, the same lava is not uncommonly glassy on the edge of the stream and crystalline inside. And here we have a little suggestion which may guide our enquiry. Everyone knows that if we aim at obtaining good crystals from a solution, the more slowly we carry out the process the better. Can it be that the slowness or rapidity of the cooling of a lava has something to do with its becoming crystalline or glassy? The observation just noted suggests that it may. We may experiment by completely melting up a lava and cooling it artificially. The result completely confirms our suspicion. Only by the slowest possible cooling can we get any crystallization to take place, and, at best, we can get only minute crystals. We have solved the problem of the varying degree of crystallisation among volcanic rocks; but a moment's reflection will show that we have raised another. How comes it that the *large* crystals occur so profusely among them? We can get nothing in the remotest degree comparable to them experimentally, though we may reproduce the structure of the ground-mass of the rock. Is it that the great mass of lava on the mountain side cools so slowly that we cannot imitate the conditions? If so, why does not the whole rock consist of large crystals? But the suggestion is altogether crushed if we examine one of the fragments of lava which has been blown out by an explosion and sent in a molten state hurtling through the air—one of the so-called volcanic bombs. This must have cooled and

solidified in a few minutes merely; yet the big crystals appear in as much force as ever. It is clearly out of the question that they could have been developed in so short a space of time, and the conclusion is inevitable: they were there already when the stony matrix in which they are embedded was still in a molten condition, while the lava was still heaving in the crater. The mind is now carried back to the deep recesses below the volcano where for untold ages the molten lava has been hidden from view. We see it now in imagination, not as a wholly liquid mass, but with slowly growing crystals floating in it. How slowly the cooling and crystallization must proceed under the vast covering of the overlying rocks the imagination is baffled to conceive; but of this we may be sure—that had it been allowed to continue, each crystal would have grown until no drop of liquid remained, and the whole would have become one mass of coarsely crystalline rock, such a rock precisely as granite is.

Here we have the explanation which Hutton already foresaw. In their deep reservoirs, lavas cool with excessive slowness, and so give rise to coarsely crystalline rock; but the same molten mass, brought to the surface, will solidify with comparative rapidity, and in a glassy or minutely crystalline condition which gives it a dull and stony appearance. The former is the "plutonic," the latter the "volcanic" phase of the same rock.

To complete the enquiry, the British Isles will serve us better than Italy. Britain abounds in volcanoes on every hand. We do not recognise them, because even the youngest of them have been too long extinct, and their cones have suffered too much from exposure through countless ages to the

elements. But, for our purpose, this is so much to our advantage. The cones are presented for our inspection in every stage of decay, dissected for us by Nature herself so that we may examine in the light of day every detail of their inner structure. Here we have exposed to view the old lava flow which had been buried for ages under later flows and sheets of ash. There is the solid plug of lava filling the old pipe through which it was rising to the crater. Running across the hillside like a ruined stone wall stands out the edge of a vertical



FIG. 4.—LION ROCK, ISLE OF CUMBRAE, CLYDE.

A weathered-out "dyke" of lava, standing as a wall-like mass of rock.

sheet of lava, which had been driven up through some rent in the rocks (see Fig. 4). Perhaps the next volcano we examine has had its entire cone swept away, leaving nothing to tell of its former existence but the old "neck" of lava in the pipe, and the "dykes" in the fissures of the surrounding rocks. In other cases even these last remnants have been removed, and the deep reservoirs of lava, now frozen into granite, exposed to view. We have, then, every opportunity of comparing lavas which have undergone their final cooling in

every possible variety of position, and of realising to the fullest extent the large number of distinct types of rock which are produced by this one varying circumstance.

The typical Vesuvian lava was rejected at the beginning of this discussion, because it differs from granite, not only in being a "volcanic" instead of a "plutonic" rock, but also in respect of the *minerals* of which it is composed. Quartz is absent. The felspar is largely replaced by beautiful crystals of colourless leucite, brownish nepheline, pale blue sodalite, or bright blue h  y  ne. In place of mica, augite chiefly occurs, while honey-yellow olivine is frequently present in addition. In petrological language these facts are expressed by describing the Vesuvian lavas as *basalts* (of a peculiar type), while the volcanic equivalents of granite are spoken of as *rhyolites*. Basalts likewise have their plutonic equivalents, of which perhaps the most familiar British examples are the rocks forming the rugged Cullin Hills of Skye. These latter rocks are known to the petrologists as *gabbros*. The difference between granite and rhyolite on the one hand, and gabbro and basalt on the other, is therefore a difference of composition. The relative proportions of the various chemical constituents is changed, with the result that when the liquid mass begins to crystallize, different minerals are formed.

The reader is now in a position to realise how great is the variety of rocks of this character. The composition is capable of almost indefinite variation, while each rock-type so produced is again capable of multiplication according to the conditions under which its solidification takes place. We see before us an immense field for study, which considerations

of space forbid us now to enter. Not only have the innumerable varieties to be compared and classified, and all their component minerals studied individually and in relation to one another, but we have also to discover how far the peculiarities of each rock are due to the varying conditions of pressure and temperature under which it solidified. We have to seek for the laws which determine what minerals shall be formed out of the homogeneous molten *magma* from which the whole rock arises. And, lastly, we have to account for the great diversity of composition which is found. We have, in fact, to discover the complete natural history of igneous rocks—for so they are collectively termed, in allusion to the “fiery” state through which they have all passed.

We have now seen what are the two fundamental types of rock which the geologist is able to recognise—the sedimentary and the igneous. In other words, we arrive at the generalisation, after hunting the world over, that every rock which is not more or less clearly built up of the worn fragments of pre-existing rocks has attained its present condition after having been in a molten state. And, since this leaves us with nothing but igneous rocks from which ultimately to derive the materials which form the sedimentaries, we finally attain the still broader generalisation that there is not a rock on the earth’s surface whose materials have not at some time passed through the molten condition. Here, indeed, is a surprising conclusion, and one which might have seemed incredible but for the known facts which have been detailed in the preceding chapter. Remembering, however, that the interior of our globe is certainly in a highly heated condition at the present time; seeing that the sun is certainly,

and the larger planets are probably in a gaseous condition; noting further that the moon shows clear proof of its former possession of great internal heat which has now vanished; and at the same time recollecting that all these bodies have had their histories closely involved and largely common, the conclusion suggested by the facts now to hand is clearly that the entire earth was formerly in a molten state. It is only just to say that the conclusion is perhaps not so inevitable as might at first sight appear, because the action of the elements in destroying the rocks is so powerful that it is in the highest degree improbable that any portion of the *original* surface of the globe now remains in its primitive condition; and owing to the alternate exposure of rocks once deeply covered, and the burial of other areas under vast accumulations of sediment, perhaps no rock is now to be found which has not, at some period or other, been more or less deeply secluded below the surface. Yet, notwithstanding that these considerations compel us to admit the bare possibility of an alternative explanation, the supposition that the now solid surface was once completely molten explains so simply the cardinal fact indicated above, and is so probable on other grounds, that little doubt need remain as to its truth.

CHAPTER IV

EARTH SCULPTURE

WE turn now to a new aspect of our subject. In the preceding chapters we have been seeking to gain an impression—necessarily a crude one—of the earth as it may be supposed to have resulted by simple cooling from its original nebulous condition. It has not been possible to do this without referring more than once to the subsequent changes which have been brought about on its surface; the problems of geology are too intricate and involved to be treated independently. Now these changes become themselves the main subject of enquiry.

The brief span of a human lifetime permits us to witness very little change in the scenes around us. Centuries are but the minutes in the life of the earth. Yet even this short time suffices to effect much. Here the storm has torn out a new gully on the slope of the hill; there the river is ever undermining its bank and slowly removing the field by its side. The ravages of the sea are evident to all. If one stands again by some estuary when the tide is out, the scene speaks volumes. There are the broad banks of sand and mud, surrounded by the brown waters of the river; out to sea, the water is clear and blue, the mud having all dropped to swell the banks. Even more striking is the case when a river flows through a lake in its course. At the upper end it may enter as a turbid stream; it

leaves again with sparkling water, the mud sinking as soon as the current is checked and adding to the delta which forms the meadow through which the river enters at the head of the lake. And so the lake is slowly filled till meadow alone remains to mark its site. The longer one contemplates this burden of solid matter carried by every river, the more one becomes impressed with the enormous waste which the land in the course of ages must suffer. It is estimated, for example, that the Danube carries every year into the Black Sea enough sand and mud to make a sheet of rock a square mile in extent, and over thirty-three feet thick, or about $67\frac{3}{4}$ million tons! The total discharge of the Mississippi may be eight times that amount!

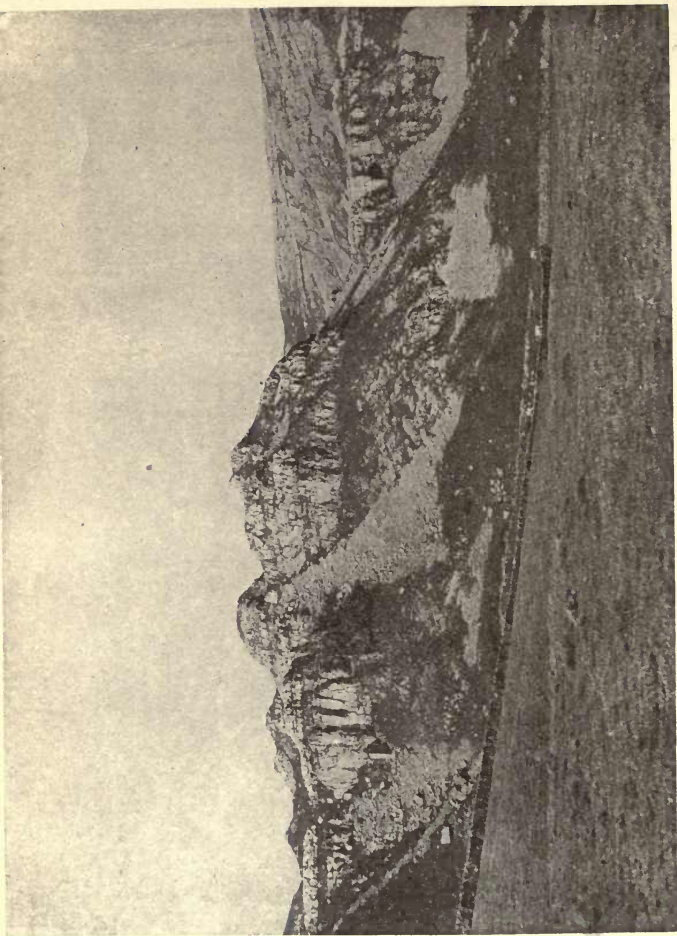
Everyone is aware of the source of much of this material. Every shower of rain produces its thousand tiny streams, each busy hurrying the finer particles of soil to the nearest brook. Even dry weather cannot prevent the waste. Scorched by the sun, the soil becomes a prey to the wind wherever protecting vegetation is absent, and driving hither and thither in dusty clouds much of it still finds its way to the river, and so to the sea. It needs little imagination to see that if the loss were not in some way made good, all soil must ages ago have disappeared.

Where the underlying strata consists of clay or soft sandy rock, nothing beyond the moistening by rain and the penetration by the roots of the plants above is needed to convert them into soil. But what of regions where underlying rocks are hard and compact? No one can have failed to observe, in quarry or road-cutting, the actual condition of affairs in such a case. Below is the solid rock, with

only a barely perceptible joint or crack here and there. Higher up, the cracks become more numerous and obvious—the rock is divided into smaller blocks. Higher still, no fair-sized fragment of sound rock is to be seen ; it is completely smashed into small angular pieces, most of which have been obviously displaced. Then this “subsoil” passes up imperceptibly by the gradually decreasing size of the fragments, and discolouration by organic matter into the true soil. Such facts speak for themselves. The solid rock below is gradually breaking up into soil, and making good the waste from above. But how ? It is a matter of common knowledge how the roots of trees seek their way into the smallest cracks and, growing there, exert great force in widening the crevices. This must clearly help in the process, yet it goes on equally where trees are absent. The organic acids, again, secreted by plants into the soil, aid in the later stages of disintegration, but are in no wise competent to begin it. Neither will the percolating rain explain the phenomena. There still remains a power as irresistible as it is gentle and elusive—the power which resides in the rays of the sun. As the rocks are gently warmed, they, like all other solid bodies when heated, slightly expand. On cooling, they shrink again. The daily changes of temperature are, of course, not felt through more than a foot or two of soil, but the influence of the *seasonal* variations is felt for many feet down. The result is clear and inevitable. In summer, the temperature of the superficial portions of the rock gradually rises, and the rock expands, while the more deep-seated parts are unaffected. The effect is that with which everyone is familiar when a piece of glass or porcelain is unequally heated—the

material cracks. Here, then, we have the primary cause of the numerous cracks, which naturally become more numerous towards the surface, where the temperature variations are more marked. But the story does not end here. Later, and more indirectly, the sun makes its influence felt still more strongly. As winter approaches, the rocks shrink and the cracks slightly gape: they become filled with water, and then, the temperature falling further, the water freezes. The sudden expansion of water when converted to ice is familiar to all. The cracks are thereby widened, only to be filled up again with water on the next thaw and the process repeated; and so on indefinitely. Should the rock itself be at all porous, the freezing of water in its minute pores may add greatly to the process of gradual disintegration. Everyone knows how effective is a frost in "breaking up" the soil itself; and it is but the same process on a greater scale which gives rise to the great "tundras" of Northern Russia—firm ground when frozen in winter; but vast death-traps in summer, because of the enormous depth of the soft soil in which man and beast may sink out of sight.

Thus it is solar heat, acting directly in the alternate heating and cooling of the rocks, and indirectly through the medium of water which freezes when that heat is partially removed, which is the real cause of all this disintegration. Yet, so far, we have been considering its action under the most unfavourable circumstances—in the lowlands, namely, where the soil is largely allowed to accumulate and so to act in the meantime as a very efficient protection to the rocks below, screening them from all the more violent changes of temperature. But let us turn to



ATEMIR, near SETTLE, showing the nearly horizontal bedding and vertical jointing of the Carboniferous Limestone, and the origin of the peaks by weathering. The smooth slopes, partly grass-covered, are screes of blocks fallen from the crags above.

Plate III.]

Photo. by R. Geiler.

the hills. On the mountain top no soil is allowed to gather; and those who have been in these lofty regions will have no difficulty in discovering the reason. There the battle of the elements proceeds with a vigour unknown in the lowlands. The fiercest lowland gale is almost a daily feature of the mountain. The rain is more abundant, and is driven with almost inconceivable fury against the rocks. The gale sweeps before it not merely dust and sand, but coarse gravel and even large slabs of rock should they chance to present a wide surface. Soil, therefore, can never gather. The bare rock itself is exposed to the fierce heat of the sun. Neither need we dwell on the greatly increased power of the sun himself at these altitudes. The heavy moisture-laden air below has not yet robbed the solar beams of their power. Hence, as every climber knows, under the mid-day sun the rocks become so hot as to be almost painful to touch; yet few nights pass without a frost. In winter, the bitter cold of every night, coupled with the abundant moisture from snows melted the preceding day, works still greater havoc. If one stands alone in the awesome solitude among the mountain crags on a clear winter day, the deathly silence is broken only by the sudden crash of a falling block, finally dislodged from its place by the last night's frost. Crash after crash tells us we are listening to the mountains falling to ruin. But our eyes reveal even more eloquent testimony, for there, on every hand, are the vast piles of boulders which one by one have fallen from the peaks above. These great "scree" are the most familiar features of mountain scenery; every gully has its fan of boulders at the bottom, every cliff has its long boulder-slope at the base.

Many a mountain, indeed, is all but buried under its own debris. These are the "everlasting hills"! One turns away with a deeper sense of human littleness.

In our own islands the mountain tops are largely protected from the attack of the winter frosts by their mantle of snow. Only the steepest crags, where the snow cannot lodge, are constantly exposed; and there, consequently, destruction is most rapid. The same partial protection is afforded all the year round to the peaks of the Alps, whose glittering mantle never completely melts away. But there the snow itself turns destructor. Year after year the snowfall exceeds the quantity melted, and the snow tends to accumulate in ever-increasing mass upon the hills. On the steeper slopes its growing weight sooner or later drags it down. A mighty mass rushes headlong down the hill, sweeping along all the loose boulders in its path, foaming through the forest or dragging the trees down in its wild career. The avalanche is no small instrument of destruction. But far more effective is the quiet and almost imperceptible descent of the snow which is left. Growing thicker until its increasing weight compresses the lower layers into compact blue ice, we then witness the strange fact that where the soft snow held firm, the solid ice begins to *flow*, and as a glacier, seeks out the valleys, and creeps slowly down till the increasing warmth melts it away as rapidly as it advances. Glaciers are the rivers which drain the snowfields; and the flow is curiously alike in the two cases. When the river comes to a steeper part of its bed it breaks into a cataract. The ice, under like circumstances, becomes cracked and broken up. The great crevasses gape open, to

close again only months later when the declivity is passed. Like the waters of the river, too, the ice carries along its burden of wasted rock. From the frowning crags by its sides the sun and frost splinter off blocks which are hurled down on to the sides of the ice to be carried along in bouldery piles—the lateral moraines—and perhaps to be tipped off in a great terminal moraine at the foot of the glacier. But, should crevasses open, another fate may await them. Under the summer sun much of the ice on the surface of the blocks left between the crevasses may melt, and the boulders may slip one by one to the bottom of the yawning chasms. There they are firmly gripped by the icy mass, which closes over them and drags them forward with it over its rocky bed, crushing them down on to it at the same time with all the weight of the ice above. Armed thus with thousands of engulfed boulders, the glacier grinds over its bed like a mighty rasp. Rocks and boulders alike are ground to the finest powder, and thus, when the ice finally melts, it issues from the glacier as a milky stream, carrying with it the powdered rock from its bed. Where the glacier has retreated from its former channel, the rocks are seen smoothed and scored. No rough crags remain. In their places are the most wonderfully smooth and rounded knolls of naked rocks—the *roches moutonnées* (sheep-backs) of the French. And by these characteristic effects, as well as in other ways, the work of glaciers may be recognised in many regions where they are not now to be found. The smooth outlines which are so characteristic of our own hills we shall later find reason to attribute largely to this action.

While the lower mountain-regions of tropical and

sub-tropical countries are not subject to erosion by glaciers, it is precisely in those parts, and especially where the air is dry and rain nearly absent, that the action of solar heat is most pronounced. In the drier regions of Africa, mid-day temperatures of 140°F. are no uncommon thing, while in exposed places the thermometer may fall a complete hundred degrees in the night. Exposed to extreme changes such as these, and robbed of any protective covering of vegetation by the continual drought, the rocks are shattered to fragments. Cracked into smaller and smaller pieces, the fragments are finally caught up by the gale and driven along till they are at length reduced to sand. So the mountains crumble down till they are surrounded by a shifting sea of sand formed from their own debris—a typical desert.

We have now seen some of the principal factors in the breaking down of the solid rocks of the earth's surface. Watched only for a day, their effect may seem trifling. In a lifetime even the change produced may be relatively small. But when we remember that these forces have been ceaselessly active not only for thousands of years but for many millions, then we may begin to realise the vastness of the changes they must have accomplished. And we shall find in the sequel ample evidence of changes vastly greater than our unaided imaginations would ever have been likely to conceive.

It remains to ask how all this mass of debris we have seen accumulating on the land is ultimately transferred to its burial-place on the bed of the sea. We already know that the rain and the rivers are the agents of transport. But, though the rain may sweep the finer soil from the lowlands into the

brooks, it is powerless to move the boulders on the mountain side. It does ultimately move them, not in a mass, but particle by particle. Everyone is aware that the weather attacks all exposed stone, with varying rapidity according to its nature. The picturesque character of an old building largely depends on the removal of the marks of artificial treatment from the stone, which exposure effects. Nowhere can the effect of "weathering" be better observed than in an old cemetery. Nothing could be more striking than the difference in the resistance to decay exhibited by the various stones, whose inscribed dates at once tell the length of their exposure. The marble stones usually crumble most rapidly. In half a century their inscriptions are likely to be entirely corroded away unless protected. Granite proves itself far more durable. Its polish may dim after ten or twenty years, but any incised lettering will usually be quite distinct at the end of a century, and it may be two or three times as long before it is completely erased. The greatest endurance, however, is exhibited by really good sandstone. Soft sandstones may crumble very rapidly, because they are porous and become a prey thereby to the frost. But provided that it is really compact and hard, the centuries pass lightly over it. One or two hundred years may produce scarcely a noticeable effect, while its records may remain legible even a thousand years.

The most familiar observations show that it is exposure to rain which causes this decay. Why the great differences in the effect produced on the different stones? In their general *physical* characters the three rocks considered do not greatly differ; the distinctions are mainly *chemical*. Marble wholly

consists of crystals of carbonate of lime ; granite, as we know, of the three minerals quartz, felspar, and mica ; sandstone almost entirely of grains of quartz. None of these substances are greatly affected by pure water ; but rain-water is not pure. It contains dissolved air. The addition of oxygen and nitrogen cannot greatly affect its powers, but the small quantity of carbonic acid gas in the air makes the water acid—a very weak acid, it is true. Now carbonate of lime is soluble in carbonic acid ; and, though the amount of this acid in a gallon of rain-water is very minute, this fact is compensated for by the large quantity of rain which in a few years flows over the stone. Each shower removes its mite of dissolved material. Even so, the process would be very slow, but for the fact that the rain eats in *between* the tiny crystals, and thereby loosens them so that they may be washed bodily away. If we turn now to a long-exposed granite we find the surface very rough. The quartz crystals stand out, while the felspars are all more or less eaten away. In time, of course, the particles of quartz must tumble out, but it is almost entirely to the corrosion of the felspar that the gradual decay of the rock is due. And so the sandstone, consisting entirely of quartz, might endure almost for ever so far as the chemical corrosion by the rain is concerned. Most varieties of this last rock, however, are very porous, and thereby yield readily to the freezing of water in their pores, or the solution of the cementing material which holds the grains together. The great importance of carbonic acid in the final disintegration of rocks is strikingly shown in the much more speedy decay of most building stones in large towns, where the quantity

of this gas in the air is considerably in excess of its normal amount.

By the chemical corrosion of the rain, then, or by the continued action of some of the other processes of destruction we have previously considered, the larger debris of the rocks is gradually crumbled down, and swept away particle by particle into the rivers and thence to the sea.

Let us turn now to the rivers themselves. Among the mountain crags, their work is far from being confined to the carrying of sand and mud. Not a little of the bouldery debris from the peaks above falls more or less directly into the torrents. Those who have never stood and watched the mountain torrent when swollen by the storm can have little conception of the power of the waters. In fine weather, only the gentle splash of the water is heard, but in spate, when the volume of the stream is suddenly increased tenfold, and its speed is correspondingly greater, the sound of the water, increased to a roar, cannot muffle the clash of the pebbles and boulders as they are rolled over or dashed along the bed. The stream is converted into a great mill in which boulders are smashed to pebbles and ground to sand. While large angular blocks are shot in at the head of the stream, only small and beautifully rounded fragments are to be found when the lower valley is reached. But not only are the boulders ground on one another. They are equally ground on the rocky bed over which the water rushes. When the spate is over and the stream reduced to its normal size, the beautiful rounded smoothness of its rocky banks testifies to the grinding they have undergone. So, age after age, the torrent runs on, ever cutting deeper and deeper into the rocks,

carving out one of those dark winding gorges which are the most exquisite feature of highland river scenery.

In the middle reaches of its course to the sea only an occasional waterfall revives the youthful vigour of the stream. Here, leaping over the edge, the waters dash on the bed below, and hurl the pebbles there collected again and again at the foot of the rock over which it is foaming. The incessant battery slowly undermines the fall until a great block crashes down from the top, only to be smashed into fragments which will be used in their turn to continue the constant undermining. So the fall gradually retreats up the river, and the valley is slowly cut deeper.

The final course through the true lowland regions has its quiet flow unbroken even by these episodes. Very occasionally an unusually severe flood may lead to the sudden carrying away of large quantities of material from its banks, but as a rule the stream meanders quietly through its meadows, carrying with it a certain amount of mud, and sweeping the sand along its bed. At each great bend the current impinges with some force on the outer bank, which is thereby slowly undermined and its materials carried away. But the immediate journey of this material is usually short. At the next bend in the reverse direction the waters of that side of the river are on the inner side of the curve, and consequently become "slack." The checking of the current at this point causes most of the material which has been picked up from the bank above to be dropped here, so that a "spit" of sand and gravel grows out at this point, to balance the loss of material which the stream is now cutting away from the other side.

And so at each bend, while the outer side is gradually cut away, the inner side grows by the deposit of material derived from the erosion at the bend above. Reference to the accompanying diagram should clear away any difficulty on this point. A little reflection will now show that the position of the river channel must be continually, though slowly, shifting; and a little extra patience will discover that

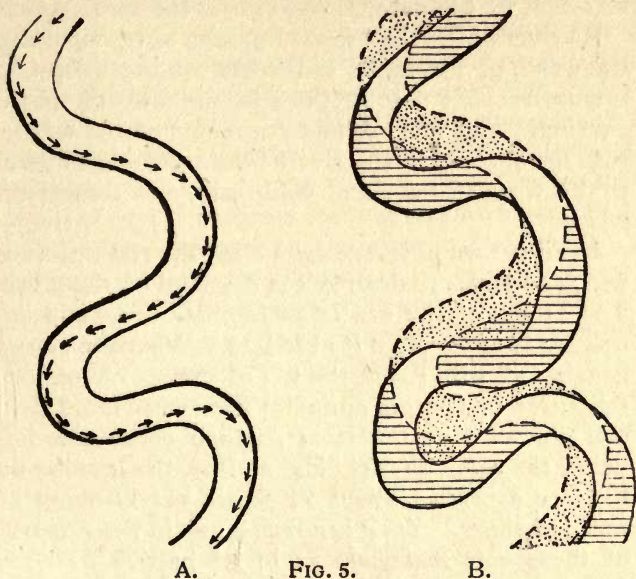


FIG. 5A—Portion of course of meandering river. The arrows indicate the course of the main current.

FIG. 5B—Course of same river at later period, changed by erosion of banks and deposit of sediment. The areas over which the meadow has been worn away are line-shaded. The growth of meadow due to deposit is indicated by dotting. Note that the curves also become constantly exaggerated, so that adjacent bends, by breach of the narrow isthmus between, may join, as would shortly take place at the lower bend here shown.

the ultimate effect is of the nature indicated in the next diagram. The bends of the river, as it were, creep bodily down the valley. Hence the deposit of material on the inner sides of the curves is only temporary. As the next bend advances down the valley it is picked up again and carried on another stage. And at each removal more grinding takes place, and some of the finer material each time will be swept by the current right on to the sea.

So rivers fulfil their great function of transporting the waste of the rocks to the sea, while performing themselves not a little work in the way of earth-carving. The making and deepening of the valleys belongs entirely to the rivers; the widening of them is the work of heat and cold, rain, and sometimes of ice.

Even yet we have not exhausted the roll of forces which conspire to destroy the dry land of the globe. The attack of the sea is so familiar that it is unnecessary to dwell on it at length. Where the coast consists of soft rocks, the toll of the waves may be measured by feet per annum. The site of more than one old town on the East Anglian coast now lies below the sea. In Bridlington Bay, the loss is said to have averaged about $2\frac{1}{4}$ yards yearly along 36 miles of shore. Yet it is not so much in the removal of these soft materials as in its battles with the sterner rocks that the waves show their power. Few scenes can rival in grandeur the wild rocky coast in a storm. When the roar drowns every other sound and the crash seems to shake the very foundation of the rocks, wave after wave retires without appearing to have made the slightest impression. And indeed they would be almost powerless against the solid phalanx of the rocks but for two circum-

stances. In the first place, they are aided by the boulders which lie at the foot of the cliff. These are caught up and flung with the greatest violence against the rocks, till their foundations are cut away and block after block falls a prey to the waves. But even more aid is derived from the fact that the rocks themselves do not present an unbroken face. The joints are the lines of weakness. Into these crevices the water is forced with all the pressure of the wave. The air is driven in and compressed before it, and when the wave retires it expands again with almost explosive violence and drives the water back. When it is known that the pressure of the waves, even in the North Sea, may be one and a half tons to the square foot, and on the Atlantic coast twice that amount, one is in some position to realise the power this action represents. The joint is soon widened to a cave, and the cave enlarged till its roof breaks down, and likely enough it joins with an adjacent cave. So the sea bores into the cliff all along the line, and gradually cuts back the coast. In this process, large pillars of cliff are frequently isolated and left standing out in the sea while the shore retreats behind them—fit monuments to mark the conquests of the waves. These outlying “stacks” are familiar objects all round our more rocky shores, and they beautifully illustrate the fact that the progress of the sea, no matter how slow, is none the less sure.

Here we must conclude this very brief and partial account of the agents which carry on the great process of rock-destruction which geologists refer to as *denudation*. When we reflect on the number of the forces which combine in the attack, when we remember the unceasing activity of every one of

them; when we know, too, that each has been busy through all the unnumbered ages since the earth became a planet, then we may well wonder how it comes that any land still remains above the ocean. And assuredly it would not be so, but for the fact that there are forces counteracting the tendency of denudation. These, however, belong to another chapter.

CHAPTER V

THE SEA FLOOR

WE have now traced the fate of the materials of the wasted rocks as far as the sea. It is time, therefore, to enquire into their later history; and this must begin, clearly, with an investigation into the manner in which they are deposited on the sea floor. The very extensive dredging and sounding which has been carried out during the last forty years over the whole world, and especially about the great highways of shipping, has put us in possession of an ample mass of the facts of the case. The whole bed of the North Sea, for example, we know to be strewn with shingle, sand, and mud. Here and there, of course, is a patch of bare rock, but these are not sufficient to affect the truth of the general statement. The same is true, again, of the English Channel, the Irish Sea, and, indeed, the whole of that submerged plateau of which the

British Isles are only the hills. For an elevation of only six hundred feet would drain all these seas, and cause the Atlantic coast to run from Norway, outside the Hebrides and Ireland, down to the Bay of Biscay. Beyond this line the existing sea rapidly deepens into the great trough of the Atlantic. In places off the west of Ireland, only about twenty-five miles separates points where the depth is 100 fathoms (600ft.) and 1000 fathoms respectively. As the deeper waters are reached, the coarse shingle and sand are soon left behind; the sediments become finer and finer, until, at about 400 fathoms, the last traces of land-mud are found. This depth, commonly spoken of as the mud-line, marks the boundary of the terrigenous deposits, as these debris of the land are appropriately termed. It may be a matter for some surprise that the distribution of these deposits should be regulated by *depth*, not by *distance from the shore*. Where the waters remain shallow, the land sediments may be carried out several hundred miles; on a rapidly deepening sea bed they are limited to a very narrow belt. But let us consider how they come to be distributed at all, why they do not wholly accumulate at the mouths of the rivers or the foot of the cliffs. We have seen that when a river enters a lake, its sediment is dropped as soon as the water is brought nearly to a standstill. So, again, the stoppage of the current on entering the sea leads to the deposit of material at the mouth of the estuary. The power of water to carry sediment depends entirely on its own motion. What movement, then, carries the sediments about in the seas?

Everyone is aware that there are currents in the ocean, the most familiar, perhaps, being the "Gulf Stream" across the North Atlantic. These are set

up mainly by the unequal heating of different parts of the ocean by the sun, in the same way that the irregular heating of the atmosphere causes the winds. But these currents are much too feeble to carry sediment. Around the coasts, however, very much stronger currents run. The strongest swimmer may be unable to make headway against these, and they are amply strong enough, therefore, to sweep before them even coarse shingle. These are *tidal currents*, and it is worth a moment's consideration to understand how they arise. The tides themselves are not currents; they are waves, in the open ocean only two or three feet high but several thousand miles broad. Now everyone knows that in an ordinary wave the water merely moves up and down. Away from the shore, a boat may dance up and down on the waves all day without being moved from its original position, so far as they are concerned. The *wave* travels along, but not the water. But this is no longer true near the beach. There the water rushes with great force along with the wave. The shallowness of the water in the latter case is the cause of its different behaviour. The actual up-and-down movement in an ordinary wave extends downwards in the water only a very few feet, and so long as it is not interfered with no other movement occurs. But as the shore is reached, the bottom does interfere with it, and a forward and backward rush of the water is the result. So with the great tidal waves. Even at depths of several hundred fathoms the natural rise of the wave entails the bodily movement of large masses of water. Hence we see that these *tidal currents* are necessarily confined to the comparatively shallow waters. As the waters become deeper they become

weaker, and herein we have the explanation of why the distribution of terrigenous deposits is regulated by *depth* and not by distance.

Sand and mud is not the only material, however, which the tidal currents have to distribute on the sea bed. No one can have failed to observe that in places the shore is largely or entirely made of sea shells. Such is the quantity of cast-off shells in the sea that it bears no inconsiderable proportion to the sand and mud. Here and there whole banks of shells or patches of shell-mud are scattered about. More impressive still are the great reefs of coral to be found round the coasts in the warmer seas, where the exquisite beauty of the corals themselves and the brilliant colouring of the profuse sea-life among them adds so greatly to the interest. In the Great Barrier Reef of Australia alone we have many thousands of square miles of coral, which must be at least hundreds of feet in thickness—it may be thousands. Coral and shell alike, of course, consist of carbonate of lime; nor is the supply of this substance limited to their productions. Many others among the more lowly inhabitants of the sea, besides shell-fish and coral-polyps, make themselves limy coats which on their death go to swell the calcareous deposits. So all these creatures toil to form the limestones of future ages.

Whence comes all the lime? The organisms themselves obtain it from the water of the sea, in which it is dissolved in small quantity; and so their ancestors have done for ages before, as the great masses of ancient limestones testify. Yet there is no evidence that the creatures of to-day have any greater difficulty in obtaining a supply than their early progenitors. The explanation lies in the fact

that the supply in the sea is restored by the rivers. Rain-water is pure, except for the gases it has dissolved out of the air; but the moment it reaches the ground it begins to dissolve the rocks, as we have already seen. Hence, when it finally flows back in the rivers to the sea, it bears with it not only the rock debris in suspension, but also a considerable amount in solution. Among this latter material, the salts lime, soda, magnesia, and potash usually form the main constituents. To the igneous rocks, then, we must ultimately trace the supply of lime which forms the shells of the sea and the beds of limestone.

We are now in a position to see, in broad outline at least, the relationship of the various sedimentary rocks to their igneous parentage. Among the long and varied list of minerals which compose those latter rocks, there is a single one which is at once abundant, hard enough to survive the eventful journey from mountain to sea without being ground to impalpable powder, and incapable of decomposition. Quartz holds this record alone; and it is for this reason that a handful of sand picked up at the river mouth consists almost to a grain of quartz. The most abundant of all the minerals of the igneous rocks—felspar—we have already noted as yielding readily to the corrosion of the rain. Its dissolved portion is the most noteworthy source of the lime, soda, and potash in the sea, while the insoluble residue is washed away as a fine mud to form the future clays. The remaining minerals for the most part are likewise decomposed or ground up, and so add their quota to the salts of the sea or the muds on its bed. Among the salts, magnesia and iron are their principal contributions.

In our sandstones, therefore, we get back the quartz of the igneous rocks; the shales and clays represent the insoluble residues of their other minerals; through the agency of the organisms of the sea the dissolved lime is extracted from its waters, and reappears in due course as limestone. This statement is, of course, incomplete, but it exhibits in a few words the main features of the grand process of the reconstruction of rocks.

The remaining dissolved materials are slowly precipitated from the waters of the sea, with one exception. The magnesia from time to time displaces some of the lime from the limestone, forming magnesian limestone or dolomite. The iron is deposited among the sediments as their great colouring agent. The beautiful red, green and yellow tints of the sedimentary rocks are almost entirely due to iron in various states of combination with oxygen and water. Soda alone remains dissolved in large quantities; owing to its high solubility it is not deposited, but constantly accumulates in the sea, and hence, as everyone knows, chloride of sodium is now *the* salt of the ocean.

It remains for us to consider that most fascinating region of the sea—the floor of the deep ocean. This was an unknown world until, about forty years ago, the problem of deep-sea sounding began to be seriously attacked. Previously, it had only been vaguely known that the depth of the great oceans is to be measured in miles. Nothing was known as to the real conditions at those depths, or as to the state of the bottom. It had been confidently predicted that life of any kind must be impossible from the enormous pressure of water and the total darkness. How far wide of the mark this prediction has proved

is now familiar knowledge. It is difficult to resist the temptation to stray from our proper path to describe the wonderful creatures which the deep-sea dredge has brought up to the light of day, to remark on their extraordinary forms and the phosphorescent organs which serve to light them in the "dark unfathomed caves." One observation, at least, we may legitimately make. It is the tendency of these deep-sea creatures to develop extraordinarily long and delicate feelers of all descriptions. Some of the prawns, for example, have all their legs many times longer than the body, and slender to a degree. No prettier testimony could be found to the unbroken stillness of these depths; such creatures would be utterly helpless in a current.

The sediments from the land, as we have seen, are all dropped by the weakening currents by the time the 400 fathom line is reached. Beyond this, the dredge in most places brings up fine, usually light-coloured mud or "ooze" of very different nature. On examination, fragments of the delicate shells of some of the shell-fish which pass a floating existence on the high-seas may usually be found—sometimes they may even form a considerable proportion of the material—but usually the eye recognises little but a fine powder. How different when a little of the mud is placed under the microscope! The grains become minute shells. Only the largest are as big as a pin's head, yet all are of the most exquisite workmanship. The most astonishing variety of form prevails; shells of one chamber and of many; straight, curved or coiled; flat or globular. Some are chalky and opaque, others like crystal. One feature characterises them all—they are perforated with numerous minute pores or

foramina; whence the name given to the group of creatures whose productions they are, the Foraminifera. But all the shells, we observe, are empty. If we would gather them with their living inhabitants we must change the dredge for the tow-net, and drag the surface waters of the ocean. In almost every part of the world they abound. The animals themselves are mere specks of almost formless and structureless living jelly, and one cannot but marvel that so lowly a creature, belonging to the lowliest of all the great branches of the animal world, should build itself so beautiful a home. But how much more strange does it seem that these most weakly of builders should be chosen by Nature to provide the mantle of sediment for two-thirds of the earth's surface—the greater part of its ocean floor!

Certain noteworthy differences are observable between the minute shells as gathered at the surface, and as dredged from the greater depths—say from 2000 fathoms. Those from the surface have all their ornament sharply defined; they resemble cut glass. They are, moreover, in many cases provided with numerous long and delicate spines, which help to keep the creature afloat. On the other hand, the shells from below have lost the clear-cut appearance, and their spines are gone. In view of the great stillness of the waters at these depths this cannot be attributed to the rolling of the shells on the bottom. It must be referred to the corrosive action of the sea-water. Besides a small quantity of carbonic acid dissolved directly out of the air, the sea is constantly supplied with this substance by the respiration of all the teeming life it contains. In consequence it is able to dissolve

—very slowly indeed—carbonate of lime. The delicate shells of the foraminifera, while occupied, are protected by the living substance which surrounds as well as fills them; but when the animal dies, or vacates the shell, this protection is lost, and as the shell slowly sinks to the bottom it is exposed during the whole time to corrosion. The minute size of the object causes its fall to be very slow—it may be only a few yards per day—so that as much as a couple of years may be occupied in the journey. Ere this time, many of the more delicate shells may be completely dissolved; and, clearly, there will be a limiting depth beyond which none will remain. It is found at nearly 3000 fathoms. This rain of foraminifera on to the bed of the ocean may be aptly compared to a shower of snow falling through warm air to uneven land. The snow reaches the high grounds before it is melted, and they become white with the fall, but in the valleys the snow is melted before it reaches the ground.

At least one great deposit of foraminiferal ooze was familiar long before the depths of the oceans, or the oceans themselves had been explored. The white cliffs of Albion are formed of just such a deposit as the ooze of the deep Atlantic. If a piece of chalk is gently crushed and the finest powder gently washed away, there will remain large quantities of foraminiferal shells almost identical with those of the present seas. The whole mass of the chalk is almost completely composed of them or their broken remains, and one may contemplate Beechy Head or Flamborough with the thought that the vast thickness of chalk which is there partially exposed to view, and which extended over some hundreds of thousands of square miles of

Europe, was the production of creatures barely visible to the eye.

These calcareous oozes of the ocean bed are not without admixture of inorganic mineral matter, as well as some organic material which is not calcareous. Those wonderful microscopic plants, the diatoms, abound in some parts of the ocean, and contribute their glassy box-like shells which they make of silica. The Radiolaria are equally minute members of the animal kingdom, somewhat closely related to the Foraminifera; they also form siliceous skeletons of the most delicate lace-like character which in places form almost pure siliceous deposits. The purely mineral matter is mostly of such a nature as to indicate that it is mostly derived from volcanic dust blown over the oceans, or from the decomposition of fragments of pumice floating over the surface.

In the deepest basins of the ocean these non-calcareous deposits alone are found. The proportion of limy matter in the oozes steadily diminishes with increasing depth, until, as we have seen, scarcely any remains below 3000 fathoms. A fine red clay almost universally occurs in the great deeps, composed of such materials as we have seen. How slowly this red clay accumulates is strikingly shown by the great quantity of remains which lies unburied on its surface. Almost every haul of the dredge brings up numbers of sharks' teeth, the ear-bones of whales and the like. How many thousands of years must it have taken for such quantities of these objects to accumulate! Yet so slow is the formation of this mud that they lie unburied still. In view of these facts it is indeed not improbable that two other sources of supply very materially

contribute to the growth of this deposit. When the shells and skeletons of the various marine creatures dissolve there will be in most cases a little insoluble residue, a kind of "ash" left over, which may still be added to the clays. And, lastly, some supply may be obtained from without the earth altogether. The shooting-stars which shower down on to the earth in thousands every day probably are not for the most part larger than grains of sand, and they nearly all reach the surface ultimately as fine dust; yet even this all but imperceptible fall of dust may add appreciably to the growth of the red clay. Thus the fineness of the sediment on the ocean floor increases regularly from the gravel on the shore to the impalpable clay in the deepest hollows.

CHAPTER VI

MOUNTAIN BUILDING

THE last stage in the cycle of changes through which the rocks pass yet remains to be considered. We have seen the primitive igneous rocks crumbling under the action of the sun and the weather, we have watched the fragments on their journey to the sea, and we have discovered the manner of their distribution over the ocean floor. We know, further, that the deposits of former days have been elevated above the sea, so that our existing lands consist very largely of rocks of this sedimentary character. This elevation completes the cycle; and a cycle it really is, for no sooner do the new deposits peer above the waves than they become a prey again to the agents of destruction, so that the whole series of events may begin anew.

The mere existence of sedimentary rocks (with often the old sea-shells in them) now high among the hills, is proof enough that the sea-level did not always have the same relation to those lands that it has to-day. But the observation gives no indication whether it is the land that has risen or the sea which has subsided. It may seem more natural to conclude that the sea has changed its level, and that view seems to have been adopted by the ancients. A fuller consideration of the facts, however, leads to the opposite conclusion. Let us note, firstly, that the positions of the sedimentary rocks are by no means the only indications of change of level. Few

persons can have failed to notice that many of our seaside towns are built on remarkably flat, low-lying stretches of ground, while the country immediately behind is frequently hilly, the hills rising abruptly from the flat. The North Wales coast furnishes perhaps the most striking examples. Almost everywhere, however, these low-lying terraces are to be found; here, it may be, only a few yards wide, there several miles. Not uncommonly, especially round the estuaries of the Forth and Tay, behind the first low terrace may be found a second at a higher level, with an abrupt step from one to the other. There may even be several of these steps one above another. A little investigation soon reveals the meaning of these terraces. Where the rocks are hard, the terrace is commonly backed by regular cliffs, on which the marks of the sea are not to be mistaken. The sea-caves are there as perfect as those on the adjacent shore. If, again, one digs below the soil of the terrace, one finds a layer of typical sea sand and gravel spread over the solid rock, out of which one may pick the shells of limpets, periwinkles, cockles, and oysters, as freely as on the sands of the existing shore. Clearly, then, we are standing on an old beach, an old terrace cut out by the sea. But when it was cut the level of the sea was evidently higher than now, or the land lower. Where we see terrace above terrace, we are evidently marking the steps by which the land rose, or the sea fell. These "raised beaches," therefore, testify to the changes of relative level of the land and sea.

The reader may be disposed to ask whether it never appears that the sea has relatively risen. Unfortunately the answer must generally be sought

below the sea. As we find on the dry land clear proofs of the former presence of the ocean, so we must search below the sea for the characteristic features of a land-surface. For movements of small extent in this direction there is very clear evidence. In the estuary of the Mersey, for example, at Leasowe, and at many other places round our coasts, a dead-low tide exposes a profusion of tree stumps and roots on the shore. The stumps, for the most part, are in an upright position, and a little digging reveals the fact that they are naturally rooted in an old clayey soil. At the locality named, also, the stumps themselves are surrounded by peat; this, in turn, is covered by another soil, at about the level of the highest tides, in which Roman remains may be found, and that soil is itself buried under the sand-dunes. Here, then, the proof is conclusive. The forest could never have grown had the older soil always been, as it is now, permanently covered by the sea. The land has there sunk, or the sea has risen. For evidence of more extensive movements in the same direction we may appeal again to the sedimentary rocks themselves. Deposits which may have been formed in deep water obviously cannot assist us, and even the finding, at depths much below sea-level, of such deposits as are normally formed in shallow water, is not quite conclusive; for very coarse materials may gather in deep water where the land dips steeply under the sea. But, fortunately, the sedimentary series includes occasional deposits which must have been formed above water altogether. The most familiar and obvious are our beds of coal. Everyone knows that coal is merely fossilised wood and other plant remains, and very commonly the bed of clay or

sandstone below the layer of coal in the pit is crowded with roots of all descriptions, including frequently the roots of large trees in their natural position. The clay is evidently the old soil in which the plants grew, and at the time of their growth it was evidently not below the sea (at least, not more below than would convert it into a swamp, which very probably was its true condition). Yet, in parts of each of our great coal fields, these beds are now found and worked at depths of two and three thousand feet below present sea level. One conclusion is now amply demonstrated: the phenomena are in no wise explained by the supposition that the sea has gradually subsided and the land emerged during past geological ages. While, for example, in central Derbyshire we have limestones which accumulated under the sea, and largely, perhaps, in deep water, now rising fourteen hundred feet above sea-level, we have also, only a few miles away in Lancashire, the beds of coal now three and four thousand feet below it. One more piece of corroborative evidence may be added to amplify the case. The land-surface receives its characteristic outlines at the hands of the various agents of denudation, and it is naturally, therefore, far more diversified in contour than the bed of the ocean. Hence we may search for sunken lands by their characteristic contours below the sea. River valleys are the most characteristic feature. Nothing resembling them could ever be produced below the sea; yet the soundings not rarely show that the actual valleys of the land do continue below the sea, sometimes for considerable distances and to considerable depths. So far as the true valley continues it marks the former extension of the land, but the

land has been submerged and the end of the valley "drowned."

The only indication among the facts just considered as to *how* these displacements have occurred is that given by the series of raised beaches. Where these are seen forming step above step it is evident that after each alteration of level there was a pause in the movement while the sea cut out a terrace. The movement in these cases was *intermittent*, but we are still left in doubt whether actual displacements were sudden or slow. Some further light may be obtained from another reference to the coal-bearing strata. In Lancashire those rocks are altogether upwards of 5,000 feet in thickness, and include several hundred beds of coal, most of which are much too thin to be of any value. Most, if perhaps not all, of these seams were formed at or about sea-level—at any rate not below it. The layers of sandstone, shale, and clay between the seams are such as to indicate that they were all formed in shallow water. Now, seeing that the uppermost layers of rock and coal were formed at or near sea-level, the lowest must then have been over 5,000 feet below it; but they, too, had been formed at sea level. The land must have sunk, or the water risen, 5,000 feet during the interval; but so slow and so gradual must have been the sinking of the land that the slow-growing sediments, *on the whole*, kept pace with it. There is still no proof that the sinking might not have proceeded by jumps of a few feet, or even fifty feet, with long pauses between while the sediment "caught up," but, averaging the whole movement of five thousand feet, it must have been extremely slow. An inch per annum would almost certainly be a very excessive estimate for the rate at which the sediments

would be deposited, and the average rate of movement must have kept below their rate of accumulation. The story which we have just worked out for the Coal Measures is only that which is repeated by the majority of the sedimentary rocks. Again and again they show that they have been formed during periods of slow subsidence of the land relatively to the sea. But again also we remember that the very fact that the land of to-day consists largely of such sediments shows that there have been periods when the movements in those same localities have been in the reverse direction. We have now reached two important conclusions: the movements were not constant in direction, and those, at least, whose duration we can estimate, occupied enormous periods in their performance.

We had occasion to remark, in the second chapter, that earthquakes are accompanied occasionally by permanent changes in the level of the ground. These changes are sudden, but they are never large. In minor earthquakes they are commonly absent or unmeasurable. After a series of earthquakes in Chili during 1822 and 1835 the coast is stated to have been raised from two to four feet for a distance of 1,200 miles. During the recent San Francisco earthquake the railway along the coast was submerged for three miles. A series of shocks affecting the Indus delta in 1819 submerged an area of some 2,000 square miles, while an adjacent area was elevated 10 feet. We have already seen that the vertical displacement along the line of fracture in the Mino-Owari earthquake in 1891 amounted in places to as much as 20 feet. This last figure must be regarded as very exceptional; even greater displacement occurred during the disastrous earth-

quake of 1692 in Jamaica, when parts of Port Royal (at that time the capital) sank 20 to 40 feet, but it has been suggested, with much probability, that this was really due largely to the "settling" of loose sand.

Among the phenomena of earthquakes, then, we have to number small permanent changes in the level of the land. Even the largest are minute compared with the vast movements the rocks evince, but if they be indefinitely repeated in the same direction they may obviously mount up to ultimate changes of any magnitude. We have already observed that the periods of time involved must be immense. The known rate at which denudation takes place gives a basis for the estimation of that of deposit, from which we may fairly conclude that growth in thickness at the rate of one foot in 500 years may not be an unfair average, while one foot per century may certainly be regarded as rapid. Evidently ordinary earthquake movements will not need to be repeated with undue frequency to keep pace with deposits growing even at the latter rate, while, as we have seen, the common occurrence of vast thicknesses of sediment, all of which have been deposited in shallow water, shows that the rate of deposit has usually fully kept up with that of movement. Such displacements as might accompany very small earthquakes, happening a few times in a century, would suffice. Indeed, we have the best reasons for believing that the subsidences and upheavals may in many cases have proceeded by stages so gentle that no shocks at all marked their occurrence. A tradition has for a very long period prevailed among the inhabitants of the Swedish coast that the sea is gradually receding from its

shores. So far back as the early part of the eighteenth century the celebrated Celsius brought forward observations supporting the contention, and after long and severe criticism it has been firmly established that the Gulf of Bothnia is actually subsiding relatively to the land, though not everywhere at the same rate. While at Stockholm the fall appears to be less than six inches per century, further north it may be more than two feet in the same period. On the other hand, in the south of the peninsula, it is the land which appears to be subsiding relatively to the sea. The truth of the matter, of course, is that in both cases it is the land which is moving, not the sea. Were the level of the water to alter, the change must be everywhere alike. Here, then, we have elevation and subsidence going on so gently that the region is singularly free from earthquake shocks, and yet proceeding quite as rapidly as the greatest movements appear to take place.

If we turn again to the rocks we readily perceive that irregularity of movement has been the rule, not the exception. The evidence is of the simplest description. Knowing that the sedimentary rocks have been laid down, sheet upon sheet, under water, we can have no hesitation in affirming the layers were originally *horizontal*. Yet we rarely find them so now. Instead, we find them inclined at every angle; in the language of the quarrymen the beds "dip" in some direction. Obviously, if the rocks have been elevated in one place and depressed in another, such tilting must be the result. Almost every section of the rocks in sea-cliff or quarry exhibits such tilting, and that to a much greater degree than might have been anticipated. A gentle

dip might be expected, but what are we to say when we find the rocks turned absolutely *on end*. Nay, further, we may even find beds turned up and forced over so as now to lie upside down. The rocks are not merely tilted, but crumpled and folded like a rucked-up carpet. The folds may



FIG. 6.—FOLD IN ROCKS FORMING CLIFF WEST OF LITTLE HANGMAN HILL, NEAR ILFRACOMBE. The rocks on the left side of the fold have been completely overturned.

be of any size. Small folds can nowhere be better seen than in the beautiful cliffs of the North Devon coast. Nothing can be more impressive than to walk along that coast, mile after mile, seeing the rocks everywhere twisted into folds like a series of great waves, folds often so sharp that the rocks on one side, as in our illustration, are actually inverted.

The mind is helpless indeed to conceive of the force which can thus have crumpled the solid rocks like sheets of paper!

The greater folds of the rocks are naturally not to be actually seen to the same effect. The Pennine Chain affords a very perfect example. That range of hills is nothing more nor less than the worn-down remnant of a great arch of rock thirty miles across, and which, if the material worn away from the top could be replaced, would be some 10,000 feet higher in the middle than at the sides. Here we have a mountain range carved out of a single great fold of the earth's crust. But the great ranges of the world are of another nature. The Grampian Hills belong to the class. Wherever we turn among those mountains, we find the rocks folded and contorted in a manner which would be perfectly incredible were it not there before our very eyes; folded not only in vast curves miles in length, but all minutely crumpled even down to microscopic puckerings. The accompanying section across those hills only illustrates the greater folds. A glance at it will convince the reader that all this crushing and crumpling cannot have taken place without causing a general elevation of the whole tract. It is evident that to produce all the folds the length of the tract must have been shortened by some miles; and what has been lost in length must have been made up for by increase in height. Of this nature are all the greater mountain-ranges of the world. They are the lines of weakness of the earth's crust, along which the forces of deformation have been concentrated to crumple up the rocks, and so to cause a great wrinkled ridge on the surface. The whole line has been elevated high above the surrounding tracts, to

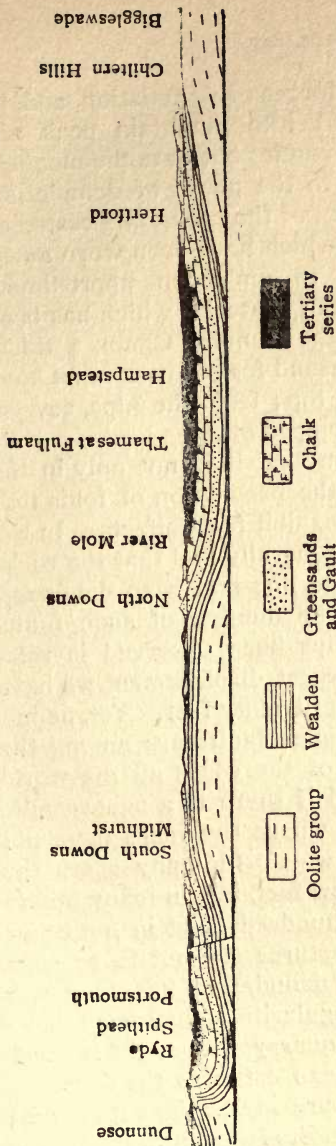


FIG. 7.—SECTION ILLUSTRATING THE GENTLE FOLDING OF THE ROCKS IN THE SOUTH-EAST OF ENGLAND.



FIG. 8.—SECTION ILLUSTRATING THE INTENSE FOLDING OF THE ROCKS IN THE GRAMPAINS. After Sir A. Geikie

become a prey to the forces of denudation, and by them to be carved out into mountain peak and valley. In passing, we cannot but note the eloquent testimony here offered to the power of denudation. By following the foldings of the rocks, and restoring the parts of the curves which have been worn away, it is a simple matter to make an approximate estimate of the amount of material which has been removed. Even from the Pennine Chain, a thickness of six or eight thousand feet of rock must have been denuded from the top; from the Alps, several miles may have been stripped off.

We have already seen that it is not only in the tilting of the rocks and the production of folds that these earth-movements exhibit their effects. In the greater earthquakes we generally find that the rocks have snapped along some line and been displaced, producing a "fault." The number of such faults whose formation has thus been observed is relatively small; and the largest displacement we have noted has been only about twenty feet. Yet, as has already been remarked, such faults are among the commonest phenomena of the rocks all the world over. It may be doubted if there is a square mile in the whole of Britain where the rocks have not been displaced in this way. In many cases the displacement is only a few feet, but in many others it is to be measured by hundreds, and in not a few by thousands. These fractures are not to be seen at the surface, because denudation has long ago smoothed away the irregularities they may have created, but in cliff and quarry we see the lines of fracture exposed, and we can estimate the displacement. The greatest fracture in Britain cuts across the whole of Scotland from Stonehaven to the Clyde,

and separates the hard rocks of the Grampians from the softer beds of the Central Lowlands. Along this line, the displacement may well amount in places to 10,000 feet. What shall we say of the force which has caused this displacement?

It must be self-evident to all that the formation of a great fault must be a process spread over the same vast intervals of time that are occupied in the slow movements of elevation and depression, or the production of great folds. Indeed, it is clear that these phenomena are but diverse results of the same movements. When one area is elevated or depressed relatively to another the result may be a general tilting of the rocks, or the production of a more or less sharp bend at some point, or the displacement may be confined entirely to a single line of fracture. Nor is this true only of *vertical* displacements. In speaking of the effects of earthquakes we remarked that the ground is frequently distorted horizontally; and we correspondingly find that the rocks on the sides of a fault are commonly displaced *laterally* as well as vertically, though, in consequence of this movement being more difficult to detect it is frequently quite overlooked.

The most stupendous and striking of all rock-movements have been in a horizontal plane. Along the sides of the great mountain-chains, where the lateral crushing has been most intense, the rocks have not uncommonly been torn across, and the sides of the range bodily crushed in under the more central portions. No finer example is known than the North-west Highlands of Scotland. The whole of what is now the coastal area has been thrust under the mountains to the east. Along some of these great "thrust-planes," where the rocks have

been sheared across, the overlying mountain masses have been forced over the rocks below for a distance of not less than *four miles*.

We have now sufficiently illustrated the nature of the movements by which the lands of the globe are raised again from the ocean grave in which the forces of denudation strive incessantly to bury them, and by which also the rocks are buckled up along their lines of weakness to form the mountain ranges, awaiting only the action of sun and rain to carve them into peak and valley. It remains for us briefly to mark the effects of this movement on the rocks themselves, and to consider wherein these stupendous forces may reside.

It can cause no one surprise to learn that the rocks are profoundly altered by the enormous pressure, crushing and shearing to which they are subjected. The most familiar example of these effects is in the conversion of clays and shales into slates. Not merely are the rocks greatly hardened, but an entirely new structure is developed in them, which causes them to split or "cleave" readily into thin plates. In other cases, the rocks have been completely broken up into larger or smaller fragments, which the pressure has subsequently compacted together again. Along with these structural changes there is usually found a considerable *chemical* reconstruction of the rock. The old minerals are largely destroyed, and new ones are built up out of their materials. This latter change cannot be due, to any large extent, to the pressure itself, but is probably stimulated by it. The ultimate cause of the change is to be found in the fact that the constituents of the rock are not (especially in the case of the sedimentary rocks)

in chemical equilibrium, while its occurrence is rendered possible by the heating to which the rock is subjected when depressed far below the surface, and by the presence of moisture, through which the minerals may be brought particle by particle into solution and subsequently deposited in their new combinations. From the joint action of all these processes there results a whole series of new rocks, by the alteration of each of the various igneous and sedimentary types. Granite is converted into gneiss, sandstone into quartzite, limestone into marble, and shales and clays into slates and schists. These are the "metamorphic" rocks.

What is the force which exhibits itself in these vast heavings and crumplings of the earth's solid crust? The geologist to-day answers this question much more cautiously than he would have done fifty years ago. The comparison of the earth to a shrivelled apple has become almost a tradition. The outer crust of the globe is now cold, and has been for many millions of years. The interior is hot, but is slowly losing heat. The natural inference, therefore, is that the interior is cooling, and if cooling, shrinking. The cold crust cannot contract, but must accomodate itself to the shrunken interior by wrinkling, like the skin of the apple. Many difficulties, however, present themselves when the theory is rigorously tested. The amount of shrinkage of the interior necessary to account for the observed folding of the crust is very considerable, and would indicate a great fall in temperature. On the other hand, the amount of heat now escaping annually can be fairly estimated, and it seems very improbable that loss at such a rate could lead to sufficient cooling in any period of time it would be

reasonable to assume. Another element of uncertainty is introduced by the enquiry whether the lost heat may not be restored. We know now that in various ways it *may* be; whether it is, we cannot tell. To the objection regarding the inadequacy of the heat-loss, it may be very legitimately answered that we really know little or nothing of the properties of matter under such conditions of temperature and pressure as probably exist within the earth; but that is merely a dignified way of saying we cannot prove the case. The second objection throws doubt on whether any case exists. For the present, the main support for the theory must be derived from the absence of any completely successful alternative. While, however, the suggestions which have been made are too complex to be considered here, there remains one aspect of the question which cannot be entirely passed over. Amid the endless alternation of subsidence and elevation affecting all parts of the globe, we find every indication that the great continents and oceans have retained their identity. In spite of every effort of denudation to destroy them, the continents are still pretty much where they were; which is tantamount to saying that through all the vagary of rise and fall, there is a general tendency for the continental areas to rise, while the ocean floors sink. The very fact that the great land-masses are able to exist at all, elevated above the ocean floor, seems to imply that they must consist of relatively *light* materials; for the enormous weight of the continental protrusions must be balanced by something, and presumably it is by the heavier character of the rocks below the ocean. Now denudation tends to destroy this balance; by its various agencies, enormous masses of material are

transported from the land and dumped on the bed of the sea. This loss of balance puts a strain upon the crust, and here, perhaps, we may see, if not one of the chief forces which cause the great earth-movements, at least one of the guiding principles which direct their action.

CHAPTER VII

THE PHYSICAL HISTORY OF BRITAIN

WITHIN the narrow limits of this little volume there is little opportunity to enlarge on the results achieved by geology in the construction of a detailed history of the earth. The barest indication only can be given of what has been learned regarding the past fortunes of the British Isles themselves; but this is perhaps not altogether to be regretted. The person whose interest in the subject ceases with the reading of geological history in books will be but poorly repaid for his pains. In proportion as the story is read in the rocks themselves it becomes vivid and absorbing.

Let us consider, then, how the facts we have learned are to be applied to the interpretation of the geological record. A few very simple considerations will supply the key. Since the sedimentary rocks have accumulated layer upon layer at the bottom of the sea, it is evident that the lowest layer must be the oldest, and the uppermost the youngest; and herein we have an infallible guide to the historical order of the rocks. So far as we can see how the beds lie one above another we can read the history at a glance. For instance, all along the

eastern flanks of the Pennine hills we may see the beds of blue limestone and shales, full of corals and sea-shells, "dipping" to the east and passing in that direction *underneath* the layers of coarse yellow grits and black shales which succeed them, and in which here a few plant remains, there a few shells, may be found. The limestones take us back to a time when that region was under the clear waters of an open sea, in which corals could flourish. The grits above tell us that at a *later* period the waters became shallow, and great rivers swept into them vast quantities of sand, in which were buried not only such shells as could live there, but some of the fallen trees borne out from the land. Above the grits in turn are found those beds of sandstone and clay among which the seams of coal occur, and in which shells of *fresh-water* species abound, together with the remains of whole forests of plants. We learn, then, that later still the accumulating sands had driven back the sea altogether, leaving broad swampy tracts on which great forests sprang up—a swampy jungle. From time to time the land subsided, and fresh-water lagoons gathered, till fresh sand and mud filled them up and allowed a new forest to rise.

In the case just considered, the story is clear and straightforward. But where the rocks have been greatly folded, or where they are covered for long distances by superficial beds of sand or clay, and laid bare only at rare intervals, it is often by no means so easy to discover what is the real order of succession, or what is the relation of the particular bed of rock seen to any other bed. For example, in very many parts of Britain isolated patches of limestone may be found which are scarcely to be distinguished in general character from the lime-

stones of the Pennine Chain; but how are we to know whether they are parts of those limestones, or whether they belong to any of the scores of other limestones which represent totally distinct periods of the world's history? The key to this problem—one of the most important discoveries in the history of geological science—was found by an engineer of Bath, William Smith, upwards of a century ago. Having traced with great care the distribution of all the various beds of rock for many miles around that town, he was enabled to make the all-important discovery that each layer of rock everywhere contained the same assemblage of fossil remains, while the fossils in any group of rocks were always different from those in the layers above or below. Thus he established the proposition that *strata may be identified by their fossil remains*. Applying it to the case of our limestones, we see that it is only necessary to examine the fossils from the various isolated patches to decide which are, and which are not, part of the same series as those in the Pennines. We see, too, in this grand discovery, not only a most valuable guide in the sorting-out and arrangement of the rocks, without which the history of the world could never have been read, but also a record of the fact that the inhabitants of the earth have been gradually and constantly changing, each period of its history being marked by its own peculiar forms of life. Fossils, then, enable us to piece together the various isolated sections of the rocks which are actually exposed to view, and to build up the whole grand sequence of the stratified rocks in its proper order. We find, when our British rocks are thus placed in order, one above another, they form a pile some

twenty miles in thickness. If the average rate of accumulation has been about one foot in five hundred years, the reader may form his own estimate of the ages which have passed while these deposits grew. In the following table, the greater groups of the fossiliferous rocks are arranged in historical order, the youngest at the top.

TABLE OF BRITISH STRATIFIED ROCKS.

Cainozoic	{ Pleistocene Pliocene Miocene Oligocene Eocene		
	Mesozoic	Cretaceous	{ Chalk Greensand and Gault Wealden Purbeckian Portlandian Kimmeridgian Corallian
			{ Oxfordian Callovian Great Oolites Inferior Oolites
		Oolitic	
		Liassic	
		Triassic	{ Keuper Bunter
Palæozoic		Permian	
		Carboniferous	{ Coal Measures Millstone Grit Carboniferous Limestone
		Old Red Sandstone and Devonian	
		Silurian	{ Ludlow beds Wenlock " Llandovery "
			{ Bala " Llandeilo " Arenig "
		Ordovician	{ Tremadoc " Lingula " Menevian " Harlech "

Pre-Cambrian unfossiliferous rocks.

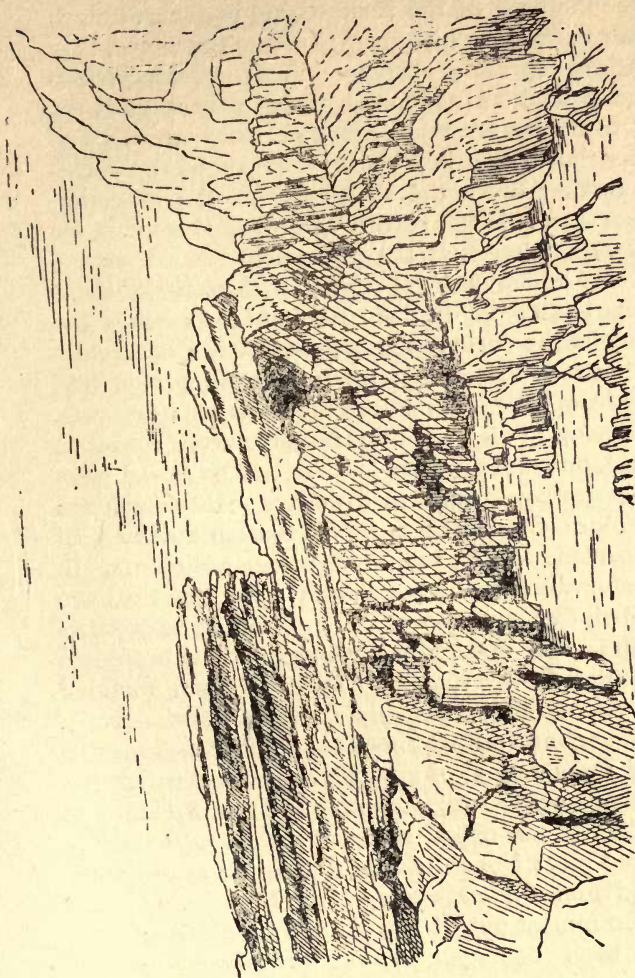


FIG. 9.—ROCKS ON SHORE AT SICCAR POINT, BERWICKSHIRE, showing nearly horizontal beds of Upper Old Red Sandstone resting unconformably on vertical Silurian slates.

The groups of rocks named in the foregoing table are extremely unequal in thickness, those nearer the base of the series being in general much thicker than those higher up; and, on the whole, they doubtless represent correspondingly greater periods of time. But, as in human history the records of the later centuries are much more perfect than those of earlier times, so it is with the records of the rocks. The further down the series we go, the more imperfect as a rule the record becomes. Moreover, we must remember that the geological record was of necessity incomplete to begin with. The site of these islands has certainly been for long ages below the sea, while the various sedimentary strata accumulated; but for periods equally long, in all probability, it has from time to time been raised above the waves. And during the latter times, not only were no rocks formed, but those which had already gathered were largely destroyed again by denudation, till subsidence once more carried them below the sea and the old land surface was buried under newer sediments. In the interval, the older rocks have not merely been denuded, but commonly tilted or folded as well, so that the newer strata have frequently been laid down horizontally over the worn edges of their inclined beds, as in the accompanying illustration. Every such "unconformity," therefore, tells of a great gap in the rocky series; of an interval during which the lower rocks were raised above the sea, folded, and denuded. The older rocks, too, have naturally suffered most from the repeated earth movements. Folded and folded again, they have often been crushed almost out of recognition, and their fossils have been damaged or completely obliterated. From one cause or another, therefore, the geological

record is most fragmentary. In the expressive language of Darwin, "we may compare it to a history of which we possess only here and there a chapter; of each chapter only a few pages; and of each page but a few lines."

With the foregoing considerations in mind, then, let us turn again to the rocks and trace some of the grander features of this country's history. The oldest rocks of these islands, the foundations, so to speak, on which everything else rests, are to be found in the extreme north-west, forming the rugged coasts of North-western Scotland, and the whole of the Outer Hebrides. That region is merely a continuation of the great plateau of Scandinavia, a remnant of the ancient axis, the old "back-bone" of Europe. Along that line, the rocks have been more intensely crushed and folded than, perhaps, anywhere else in the Old World. And so our history begins, as is inevitable, among its greatest difficulties. The rocks are so altered that scarcely a trace of their original character is to be found. They are so folded that no order in their sequence remains. It is nearly certain that they never had any fossils, but if any were there no sign of them is left. We believe them now to have been for the most part igneous rocks of a volcanic nature, vast sheets of lava, the products of immense primæval eruptions. The one fact which is abundantly evident is that these "Lewisian" rocks (after the island of Lewis) were very early subjected to the most powerful earth movements, and folded and altered to almost as great a degree as they are at present, long before Cambrian times. After their folding, further volcanic activity is evinced by innumerable "dykes" of lava which penetrate them. In turn, we find

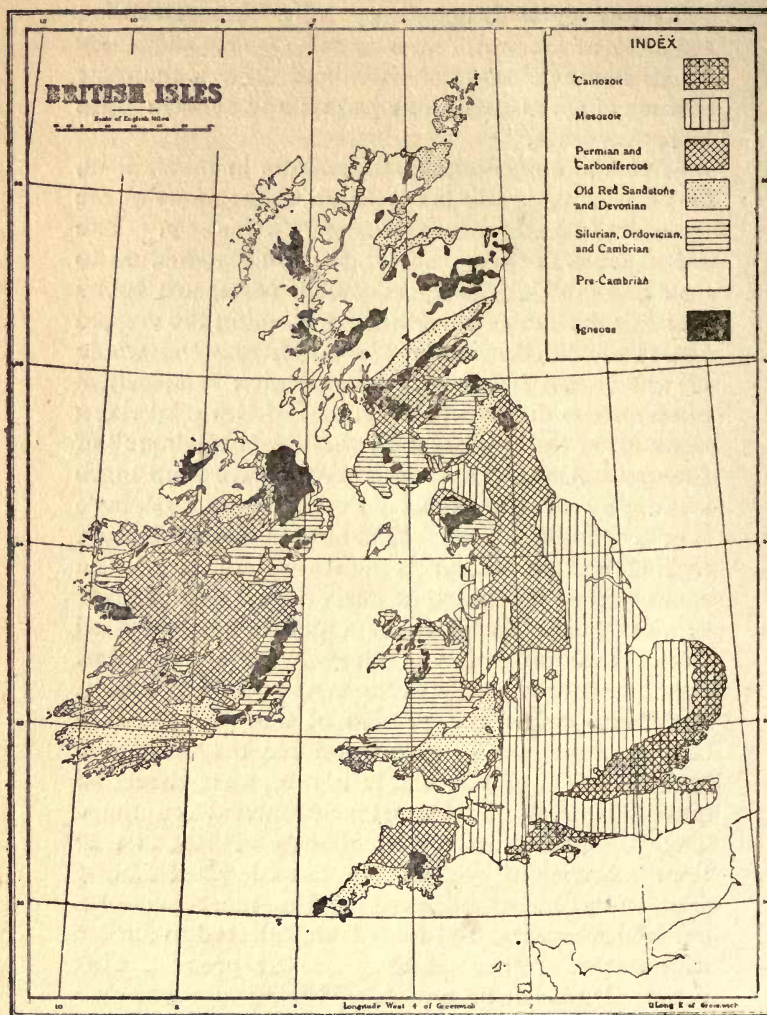


FIG. 10.—GEOLOGICAL MAP OF THE BRITISH ISLES.

evidence of a second period of folding, which affected the dykes as well as the older rocks. Then there must have followed an immense space of time while all these rocks were exposed to the ceaseless attack of the elements, by which the great mountain range into which they had been folded was worn down to its roots. There is some evidence that almost desert conditions prevailed, and the valleys were slowly filled with the debris from the hills. So accumulated the vast piles of sand and gravel, in places not less than 10,000 feet thick, which now form many of the drear forbidding hills of the North-west Highlands. Below these sheets of now solid rock we may still follow the outlines of some of the old land they buried, the oldest surface of this country of which any trace remains.

What lapse of ages the events just narrated may represent we have little means to judge. We only know that they had all transpired, and the "Torridonian" sands and gravels (from Loch Torridon) had become hard rock, and been themselves carved out into hill and valley, before the beginning of the Cambrian period. We know, too, that in other parts of the country great changes had occurred. Subsequently, in all probability, to the formation of the Lewisian rocks, the whole area of these islands, perhaps, had been below the sea, and in that sea were deposited the sheets of sand and mud, with bands of limestone which now form almost the whole of the Grampian highlands, as well as the ancient rocks which in many other parts of the country peep out from below the younger sediments. But these rocks, too, had suffered so profoundly from the earth-movements

that their primitive character is almost entirely lost. The shales were altered to slates and glittering crystalline schists, the limestones to marbles, the sandstones to hard quartzite. We cannot but believe that they once enclosed the fossil remains of the strange creatures of these early oceans. Yet no trace of them is now to be found. Volcanoes poured out their lavas over the sea-beds, or intruded them among the sediments, while deeper down, the intruded molten masses cooled to form the granites of to-day. Among Britain's truly ancient mountains we have the mutilated and almost obliterated records of the early history of the country. Here and there we may decipher a fragment, but most of the story of those early times must remain forever a part of the great unknown.

From the lowest Cambrian rocks upwards, we have the invaluable aid of the fossils to guide our enquiries, and the main features of the subsequent history are known with certainty. Before that period began, it is clear that all the older rocks had been greatly worn down by the elements. Wherever the base of the Cambrian system can be traced, it rests on an irregular surface of the rocks below—the second surface which we know this country to have possessed. The Torridonian rocks, for example, had been in many places completely worn away again. The Cambrian rocks themselves consist, in Wales, from whose classical name their title is derived, of sandstones and slates (the latter altered shales) containing a great variety of marine fossils. In North-west Scotland, nearly two thousand feet of limestone is included in the system. On the whole, however, we may be confident that

these deposits were accumulated in fairly shallow water, and as they reach in Merioneth a thickness of upwards of twelve thousand feet, they therefore clearly point to a gradual subsidence of the seabed. And further, as these deposits occur in the south and north of Wales, in Shropshire, and the Malvern Hills, in parts of Ireland and north of Scotland, it is fairly clear that the Cambrian sea must have extended over the greater part of these islands, though the rocks are now in most parts either hidden under newer deposits, or completely worn away again.

The Cambrian subsidence continued without serious interruption throughout Ordovician and Silurian times, and to such an extent that no less than sixteen thousand feet of the former and five thousand feet of the latter rocks were deposited. The fineness of the mud which forms some of the slates and shales of these systems would seem even to indicate that the water over some areas was at times of considerable depth. Yet the evidence that some areas remained above the water, in spite of the prolonged denudation to which they must have been subjected, proves also that the subsidence was not universal. In places, the country must have been actually rising, and we must conclude, as usual, that what was really occurring was not a bodily subsidence of the whole region, but rather a slow *folding* of the earth's crust. There is no doubt, however, that during this immensely long period, the greater part of the British area remained almost continually below the sea, with only scattered islands peering above its waters; by far the longest period of uninterrupted submergence of which we have a certain record. The

Ordovician rocks, which attain their greatest development in Central Wales (and are named, therefore, after the territory of the ancient Ordovices) consist, like the Cambrians, mainly of sandstones and slates, the famous slate-quarries of North Wales begin mainly opened in them. Among the Silurian beds (from the country of the Silures, to the east of Wales) several thick bands of limestone occur, often full of fossil corals. So abundant, indeed, are the corals, that some of the beds have been well described as fossil coral-reefs.

The advent of the Ordovician period was marked by great and widespread outbursts of volcanic activity. All over North Wales and in the Lake District volcanoes arose. Nearly the whole of the Cader Idris range, and much of the Arenig and Snowdon ranges, is composed of sheets of lava and volcanic ash ejected at this period. In places, the aggregate thickness of the volcanic materials is not less than six thousand feet. The volcanoes clearly, were of the first magnitude. Yet the eruptions of the Lake District far exceeded those of Wales. By far the greater part of the Cumbrian group of hills is carved out of a continuous mass of volcanic material which is estimated at from ten to fourteen thousand feet in thickness. Even the portion of the lavas now exposed extends over an area about twenty miles by twenty-five, and this is evidently but a small part of their original extent. Thus, as one stands on the summit of Scawfell or Helvellyn (both carved entirely out of this material) and looks over the surrounding hills, one sees on every hand the products of one of the greatest volcanic outbursts this country has ever witnessed. Throughout the Ordovician period local eruptions

continued, but the first great effort was never again equalled. By the Silurian epoch, quiet was completely restored.

The prolonged subsidence of most parts of this country, which had kept them for ages below the open sea, at length ceased, or at least became slower and less general. The waters became everywhere shallow and perhaps land-locked, and the creatures of the open sea were no longer able to live in them. Under these conditions thick masses of coarse sandstone and marl accumulated, in those areas where subsidence continued, to form the Old Red Sandstone system. The formation of these rocks may have been comparatively rapid, seeing that the area of land exposed to denudation in the immediate neighbourhood was now much greater than during the preceding periods. Yet, when we find these sandstones sometimes upwards of 16,000 feet in thickness, we must allow that they represent an immense lapse of time. During this period, again, the volcanic fires broke loose, this time principally in Central Scotland; and the Sidlaw and Ochil Hills, among others, are mainly composed of their lavas and ashes. One part of the country remained throughout below the open sea—the extreme south. In that region beds of sand, mud and limestone, full of marine shells and corals, continued to gather, while elsewhere the Old Red Sandstone was forming. Everyone must be familiar with the beautiful so-called “marbles” of Devonshire, so largely quarried and used in polished slabs for ornamental purposes, which are the limestones of this “Devonian” system.

The continued earth-movements at length raised the entire country, except possibly the south, com-

pletely above sea-level. For the third time, at least, the British area became part of the great continent, The Old Red and Devonian rocks, along with all the older ones, were greatly folded, and exposed for a prolonged period to denudation. In many parts, thousands of feet of rock were worn away during this "continental" period, and the whole region was carved anew into hill and valley. Hence it was a very uneven land-surface which at length subsided again below the ocean, and over which in due course the Carboniferous rocks were laid down. The submergence began in the south, and there the corals, sea-lilies and shells began to build up the Carboniferous limestone while the central and northern parts of Britain were still above water. The shoreline crept slowly northward, the advancing sea converting the hills into islands, and ultimately submerging them. At the foot of the Grampians the onward march of the sea was stopped, and throughout the Carboniferous period great masses of land persisted in that direction. The succession of events during this age has already been noted—the shallowing of the sea, and consequent covering of the limestone with great sandbanks, now forming the Millstone Grit, followed by the conversion of the whole tract into a swampy jungle which periodically subsided, but was repeatedly brought above water again by new accumulations of sand and mud, and whose successive coverings of vegetation are now preserved to us as beds of coal. Already, before this formation of the Coal Measures was complete, renewed "warping" of the country began, raising some areas into high land, while others were depressed and became covered with land-locked arms of the sea. The Pennine Chain is one of the

ridges produced at this period. In the enclosed seas the Permian rocks gathered. To the east of the Pennine ridge some limestone was formed, but to the west bright red sandstones and clays alone gathered. Meanwhile, the ridged-up Carboniferous rocks were extensively denuded, and the Permian strata in many parts rest over their worn edges. The waters of the enclosed seas became intensely salt, supporting only a dwarfed assemblage of living creatures and leaving deposits of salt and gypsum here and there among the sediments.

Again Britain was raised completely beyond the reach of the waves, in common with all Central and Northern Europe, for its fourth known period of continental existence. So far was the region thoroughly continental at this time, that, for a lengthy period, desert conditions appear to have prevailed. In this desert, the "Bunter" ("mottled") sandstones of the Triassic system were formed. This soft sandrock, with its warm yellow and red tints, is a well-known feature in the Midland counties and elsewhere. Subsequently a great Y-shaped lake gathered in the desert, its arms enclosing the Pennine area, and its "tail" reaching at least as far as our present south coast. Perhaps, like the present Lake Chad in the Sudan, it was a mere film of water which often entirely vanished. That it did so at times is sufficiently proved by the fact that the animals of the period roamed about and left their footmarks all over its bed. Certainly it became intensely salt, and the famous salt-beds of Cheshire were deposited from its waters. Its chief relic is the thick mass of bright red clay which forms the upper portion of the Triassic system.

Throughout the remainder of the Mesozoic epoch,

Britain was reduced to an essentially insular condition, though no doubt it was now and then connected with such parts of the continent as happened to be above water. Subsidence during this period took place mainly in the eastern and southern parts of England, while the rest of the British area was doubtless, on the whole, rising; only small parts of it being, from time to time, submerged. In the south-eastern sea, beds of sand, clay and limestone gathered in the most varied succession, pointing to an oscillating sea-level, and giving rise to the varied series of rocks which now characterise that portion of the country.

During the Liassic part of this period, the sea spread widely over these islands, but later, in early Oolitic times, the land-area became more extensive. The north-east of England at this time was the site of a great estuary, till subsidence once more gained the upper hand in that area, and carried it below the sea of the Upper Oolites. At the beginning of the Cretaceous period the conditions were reversed. The south-east of the country was now an estuary, opening eastwards, while the more northern parts were under deep water. This latter state of affairs was shortly followed by the closing scene of the Mesozoic epoch, when all the centre and south of Europe, levelled down by the long-continued denudation, sank deeply to be covered by a great "epi-continental" ocean—the ocean of which our present Mediterranean is the last diminished remnant. On the bed of this ocean there gathered vast deposits of fine grey ooze, in essential characters like the ooze which is gathering to-day on the bed of the Atlantic, and formed, like it, mainly of countless myriads of the microscopic shells of

Foraminifera. That ooze now forms the white chalk cliffs of Albion.

We come now to the thoroughly modern ages of geological history. The general subsidence of the Chalk period was closely followed by an equally wide-spread elevation. Europe resumed its full continental form, and included Great Britain within its bounds. Very extensive geographical changes clearly took place, which resulted in the invasion of Europe by entirely new forms of life, both animals and plants. For a very long period Britain remained entirely continental. The Eocene rocks, however, mark the encroachment of the sea over the south-east of the country. At first, continuous shallow sea stretched from the Humber to Portland, but later it was divided by the elevation of a ridge which now forms the watershed between the Thames basin and the rivers of the south. The rising of this arch above the waves was the first sign of a series of great earth-movements which culminated in Miocene times. In Britain itself, the chief result of these movements was the formation of this fold (of which the North and South Downs are, so to speak, the worn edges) and the elevation of the entire country above the sea before the Miocene period. But on the continent, far more stupendous effects were produced: nothing less, in fact, than the formation of the Alps themselves, which were then raised to their present eminence, or perhaps much higher. Could we have been present, nevertheless, it would not have been the raising of the Alps which would have impressed us. Apart from earthquakes, that would have been imperceptible. On our own western shores much more striking phenomena would have borne witness to the unquiet state of

the earth. From Ireland to Iceland one long line of volcanoes broke out, with all the vigour which characterises a series of eruptions following a long period of inactivity—for the whole Mesozoic period had been unmarked by a single outbreak. Indeed, unable to escape rapidly enough through single vents, the lava rose at times simultaneously through countless fissures in the rocks, and buried thousands of square miles of country under vast lava-floods. Almost the whole of the county of Antrim is underlain by one of these lava-sheets, or rather by a small remnant of one, while Arran, Mull, Skye, and many other of the Western Isles of Scotland are largely the worn-down stumps of the volcanoes.

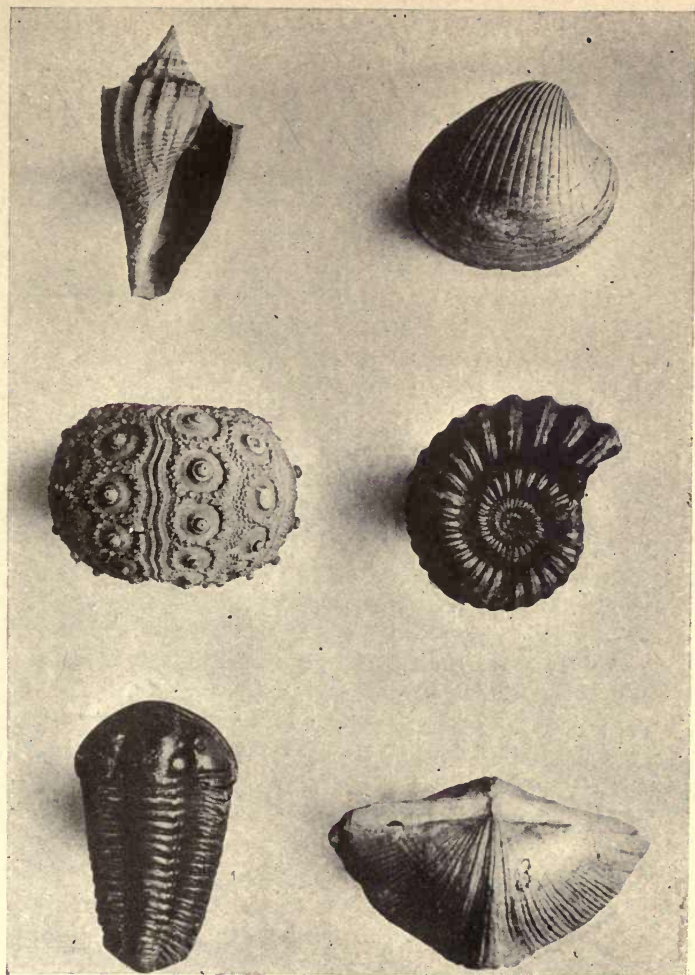
We have noted that during Miocene times Britain was entirely above the waters of the sea. When East Anglia sank again under the early Pliocene sea, considerable changes had occurred in the marine life since Oligocene times. While at the latter period the local sea-fauna had an almost tropical aspect, it had now become temperate in character. The climatic change continued throughout the Pliocene period. At its close, the climate was almost arctic, and became thoroughly so in the early stages of Pleistocene history. We may imagine the snow gathering on our mountain-tops, and the glaciers forming and creeping ever further down their sides. The valleys were filled with ice, which united in vast sheets over the lowlands till the whole country north of the Thames and Severn was buried under one vast ice-field as completely as modern Greenland. All Central and Northern Europe lay under the same icy mantle, and the British ice united with that of Scandinavia over the bed of the North Sea. For many thousands of years the

surface of this country was ground and polished under the slowly streaming field of ice, and the smooth outlines which now characterise British scenery are certainly due in no small measure to this Great Ice Age. While the ice still persisted, a general submergence of the lowlands appears to have occurred. Into the water the ice dropped pell-mell its burden of sand, mud and boulders, thus covering the country with that superficial coating of sand and gravel which to-day hides the solid rocks almost everywhere except among the hills, and out of which thousands of ice-scratched boulders may be gathered. Slowly the country rose again, the climate ameliorated, and the ice shrank back into the hills. During their retreat, the glaciers left many a moraine of debris behind them, still to be recognised in hundreds among our highland valleys. The sea left its mark in the raised beaches round our coasts, and so the country reached the condition in which we now find it. The story of Geology is ended; the work of the antiquarian and historian begins.

CHAPTER VIII

THE HISTORY OF LIFE ON THE EARTH

BRIEF and fragmentary as these sketches of Earth-history necessarily are, we cannot conclude them without a reference to the most fascinating story which the rocks contain—that of the life of former ages. We saw in the preceding chapter that each great stratum of the sedimentary rocks contains its own peculiar assemblage of fossil remains, which differ from those of any other stratum, but are generally most similar to those in the rocks immediately above or below. Thus, while the organisms found fossilised in the uppermost (and therefore newest) strata differ very slightly from the creatures still living in the same region, those in the successively lower (and therefore older) rocks appear more and more unlike the existing forms, until, in the oldest rocks, we find ourselves among the most strangely unfamiliar and most primitive creatures. Moreover, in our receding glance, we lose sight of whole groups of animals one after another; and it is always the most highly developed creatures which are the first to be lost in our backward march. These few simple facts—that the inhabitants of the world have *gradually* changed, that there has been a constant approximation to the forms now living, and that the groups of animals low down in the scale of life have always appeared before those of a higher organisation—are the grand features of the support given by Palæontology (as



TYPICAL FOSSILS.

1. Trilobite crustacean. *Calymene Blumenbachii*,
Wenlock Limestone.
2. Brachiopod. *Spirifer striatus*, Carboniferous Limestone.
3. Cephalopod. *Ammonites (Ægoceras) capricornus*, Lias.
4. Echinoid. *Cidaris florigemma*, Corallian.
5. Gastropod. *Voluta luctatrix*, Eocene.
6. Pelecypod. *Cardita planicosta*, Eocene.

the study of extinct creatures is called) to the doctrine of Evolution. If life has been continuous on the earth from the beginning, and if every new form which has appeared has resulted from the slow modification of some preceding form, then the significance of those facts is clear; if not, then the whole of palæontology and biology is unintelligible and incapable of scientific explanation. With these few introductory remarks, let us turn to the rocks to learn a few of the facts they have for so many ages preserved for us.

In the most ancient strata in which fossils are still to be found in a recognisable condition, we meet already with a large and varied assemblage of organisms. Nearly all, that is to say, of the great groups of animals lower in the scale of life than the Fishes, are represented, though for the most part by forms very different to those now living. The question naturally arises, therefore, how all these forms came to be evolved so early? In reply, the geologist points to those great masses of altered rocks, for the most part crushed and twisted almost out of recognition, of which we can only say that they were formed before the Cambrian period. That many of them once contained relics of still earlier life, now destroyed, is practically certain, and the high development of life in Cambrian times only confirms what on other grounds seems probable—that many as must be the millions of years which have elapsed since the Cambrian rocks were formed, the period which preceded it must have been fully as long. All, or nearly all, of the history of those earlier times has been irretrievably lost by the alteration of the rocks and consequent obliteration of their records.

The lowliest organisms have played no inconsiderable part in the past history of the world. In the oldest fossil-bearing rocks the almost microscopic shells of the Foraminifera are found, while they have contributed not a little towards the building of the limestones of various ages. The Chalk, we have already seen, consists not uncommonly mainly of their remains, though some thousands of their shells may be gathered in a thimble; and the Tertiary limestones of Egypt (of which the pyramids are built), and some of the Eocene limestones in the neighbourhood of Paris and elsewhere in Europe are formed largely of the shells of giant members of the race. To the palæontologist, however, the fossil foraminifera are of interest mainly as illustrating the persistence of lowly forms of life. While the higher creatures come and go, changing more rapidly in proportion to their complexity, these simple creatures persist from age to age, almost unchanged by the hand of Time. Even in the Palæozoic rocks, the foraminifera have a remarkably modern aspect, some of the forms being scarcely distinguishable from those now living, while the higher creatures whose remains are preserved in the same rocks are all unfamiliar.

The Corals, too, we have noted as rock-building creatures in all ages. More highly organised than the Foraminifera, they have undergone greater changes during their history. The group which includes the typical reef-builders of the present day did not appear in the world till the early part of the Mesozoic epoch. Their ancestors were already living in Ordovician times, and certainly long before, but they were in some respects different from the modern forms. While the latter build skeletons

which are usually radially symmetrical, their palæozoic ancestors formed skeletons of a bilateral character, *i.e.*, with distinct right and left halves. In this change the corals exemplify a modification which has nearly always come over animals which have adopted a sedentary mode of life. Fossil corals are among the most familiar of objects. Our mantel-pieces and other objects of coloured "marble" (really limestone) seldom fail to show the beautiful lace-like forms of the corals they contain. Especially is this the case with the well-known red marbles of Devonshire.

The "precious corals" of to-day belong to a group which has long since passed its prime. Though now comparatively rare, their ancestors abounded in the Palæozoic seas, and contributed largely to the coral reefs of those early ages.

Of shell-fish (apart from lobsters, shrimps, etc.) there are two widely distinct classes. The Mollusca include all the common sea-shells and land-shells of the present day, and are now in the prime of their existence. The Brachiopoda, or "lamp-shells," on the other hand, are rarely seen by the ordinary person outside a museum. Yet it is to the latter group that by far the greater number of the countless shells found in the Palæozoic rocks belong. (See Plate iv, fig. 2.) We have here another group of animals whose day is long past; and we may learn from them an oft-repeated story. During their prosperous days they gave rise to many varied and complicated forms; yet the few which survive are relatively simple. Again and again we are faced with the same fact. Highly complex and specialised organisms may succeed in the struggle for existence for a time, but it is the relatively simple organisation which endures.

The Mollusca are represented by their three chief groups in the earliest fossiliferous rocks. The two simpler groups, viz., the "Bivalves" (including oysters, cockles, etc.) and the "Univalves" (or snail group), have steadily increased in variety, complexity and numbers throughout past ages (see Plate iv, figs. 5 and 6). It is the highest group, again, represented now by the cuttle-fish, octopus, and nautilus, which ran through its development most quickly, and is to-day in a very decadent condition. In Palæozoic and Mesozoic times these "Cephalopods" were much more abundant. The great family of Mesozoic cephalopods—the Ammonites—are probably the most familiar and popularly prized of all fossils. The beauty of their volute-like shells is seldom excelled, while their exceeding abundance ensures their familiarity. (See Plate iv, fig. 3.)

The history of the great group of animals to which the star-fish and sea-urchins belong—the Echinodermata—is very fully recorded in the rocks. While the primitive stock consisted of more or less globular or egg-shaped creatures, covered with an irregular mosaic of calcareous plates, they developed along a variety of diverging lines, after having first become a typically sedentary group and acquired in consequence a general radial symmetry. Some, becoming first more definitely globular, and developing great regularity in the arrangement of their plates, arming themselves all over at the same time with an elaborate defence of spines, gave rise to the existing group of the sea-urchins, which in later times have in many cases lost their spherical form, becoming more or less flattened or even biscuit-shaped (see Plate iv, fig. 4). Another series, having many of their covering-plates reduced to

mere nodules in the skin, and developing also five finger-like lobes or "arms" to the body, became the starfishes. But a much more striking series of modifications began with the attachment of some forms to the rocks of the sea-bed by means of a flexible jointed stalk. Subsequently, these attached forms developed a set of five jointed, slender, and often much-branched feathery arms, the whole creature thus becoming very plant-like in appearance. A few of these "sea-lilies" or Crinoids still exist, mostly in the deep sea—the refuge of many "living fossils"—but they reached the height of their glory in Palæozoic times, and not a little of the Carboniferous limestone of the Pennine Chain is mainly composed of their jointed stems.

Passing now over the remainder of the lower forms of life, let us turn to the higher creatures, whose geological history must ever be of the greater interest to the palæontologist and to the student of evolution. This must be the case for two reasons: in the first place, the history of the higher animals is or will be known *from the beginning*: while the great groups of the lower animals had all been evolved before the period at which the geological record begins to be legible, so that we can only trace the details of their subsequent modification. The starting point of each of the higher groups, from the fishes onwards, lies within the range of known geological history. Secondly, the structure of these more advanced forms can be known with much greater completeness. In the case of the lower animals, the only part capable of preservation in the fossil state is usually some form of shell, or external covering, which as a rule conveys little information as to the structure of the real living

tissues of the animal. On the other hand, as everyone knows, the higher forms possess an internal skeleton, consisting of a skull, back-bone, and supports for the limbs; and the bones of this skeleton are related so intimately to the structures around them that it is possible, from their study, to reconstruct almost every detail of the animal's body. The muscles, nerves, and blood-vessels can all be restored with more or less completeness, and the dry bones made to live again.

The fishes present many points of interest in their past history. The gradual elaboration of their scales, teeth, fins, tails, and general skeleton can all be more or less perfectly traced, though most of these features require some technical knowledge for their comprehension. Being much the most primitive of the vertebrate animals, the fishes are naturally the first to appear in order of time—viz., during the Silurian period. In the same connection it is of interest to note that the simplest group of the fishes is the earliest to be developed and elaborated. The class which contains the sharks, dog-fish, and skates is in many respects more primitive than the great mass of living fish. While the majority of fish, like all higher animals, have a skeleton of bone, the shark class has only cartilage, which never becomes replaced by bone as in the higher forms; and it is to this cartilaginous or "shark" class that nearly all the early fossil fish belong. In the Palæozoic period they formed the dominant group, while it was only in the Mesozoic period that the "bony" fish became abundant. Of still greater interest is an even more primitive group of so-called fishes—for it may be doubted whether they ought to be classed as fish at all—the hags and

lampreys. This little group is the sole remnant of a class of primitive vertebrates which had a short but brilliant career during the Silurian and Old Red Sandstone periods, while fish life, if we may so put it, was still in a very experimental stage. Seldom has any group of creatures produced more truly archaic-looking forms than these relatives of the hag-fish in the Old Red Sandstone waters. Yet many of the other contemporary fish were little less remarkable, the entire Old Red Sandstone group forming a most fascinating collection. Those fish enticed Hugh Miller to geology, and the reader may still turn to his "Old Red Sandstone" and "Footprints of the Creator" for the most lively accounts of them.

Geological history is still silent regarding perhaps the most notable event in the history of life on the earth. We can only surmise that sometime previous to the Carboniferous period, probably during the preceding Devonian times, some type of fish acquired the power of breathing the oxygen in the air, as well as that dissolved in the waters, and at the same time had its paired fins modified into true limbs which enabled it to crawl on to the land. Meantime we must patiently wait the day when some fortunate blow of the hammer shall disclose the remains of these forerunners of the amphibia, reptiles, birds, and mammals. The earliest Carboniferous and perhaps the highest Old Red Sandstone strata contain the footprints of four-footed creatures—the first traces of them yet found. Somewhat higher in the Carboniferous rocks the first skeletons of the amphibia occur—salamander-like creatures, of very varied size. In many respects these early amphibia were more primitive

than their living descendants. In particular, many of them appear to have breathed during youth by means of external gills, like the tadpole of the frog. They show also many other curious points of resemblance to certain of the Old Red Sandstone fish in the—form of their teeth, the development of certain protective plates in the eye, the arrangement of the bones in the skull, and the presence of scaly plates over a portion of the body—resemblances which can scarcely be altogether accidental. While some of these early amphibia were no bigger than a modern newt, others became very large and massive, one having a skull no less than four feet in length.

The most highly developed of the Palæozoic amphibia grade almost imperceptibly into the most primitive of the reptiles, which make their first appearance in the Permian rocks. This transition from the amphibia to the reptilia is made doubly interesting by the fact that the reptiles themselves almost immediately gave rise to forms which present the most remarkable resemblances to the mammalia in almost every part of their anatomy, resemblances so strikingly complete that some of the best authorities now believe that these primitive reptiles were the direct ancestors of the mammals. To this point, however, we must return later.

The history of the reptiles is undoubtedly the most romantic of any group of organisms. The person whose knowledge of the group was confined to the living crocodiles and alligators, tortoises, turtles, snakes, and lizards, would little guess that the reptiles had once attained a dominance over the world such as no other group of animals has ever approached. Immediately on their appearance in the world they evinced a most wonderful capacity for modification and adaptation, and so gave rise to forms suited to every kind of environment and mode of life. Fleet, agile forms more delicate than the cat or the deer were associated with powerful massive creatures more reminiscent of the hippo-

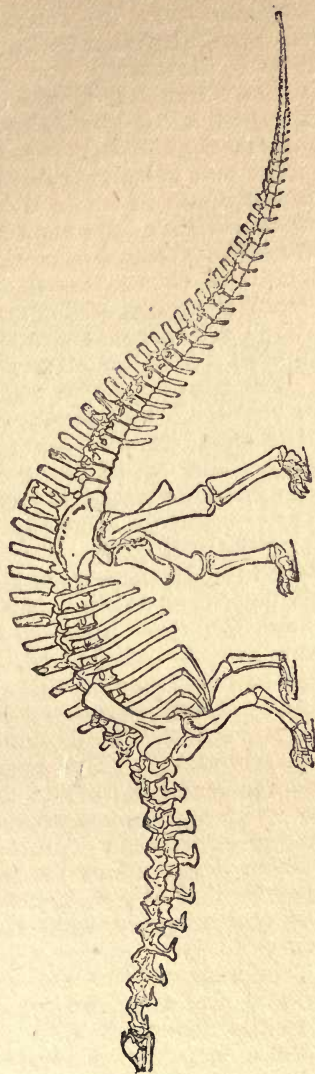


FIG. 11.—SKELETON OF BRONTOSAURUS, A DEINOSAUR, FROM THE
UPPER JURASSIC OF WYOMING. Length about 60 feet.

potamus or the elephant—and the variation in size was much greater. Several groups became modified for amphibious, and ultimately for completely aquatic life. On the other hand, one group, the Pterodactyls, developed a bat-like form and gave rise to a large number of flying reptiles. Two groups of these creatures quite overshadow all the others in the magnificence of their development. Some of the Deinosauria have long been familiar to English readers from the classic descriptions by Dr. Mantell of the remains of *Iguanodon*, *Hylæosaurus*, and other forms from the rocks of Tilgate forest in Sussex. But perhaps few persons would be more surprised than Mantell, could he return to review the Deinosaurs now known. The name, which signifies “terrible reptiles,” was appropriately applied to the forms first known—reptiles ten or fifteen feet in height, and much more in length. How much more appropriate would it have seemed had the American *Brontosaurus*, sixty feet in length, been then known; or the still larger *Atlantosaurus*? We need scarcely add that they were the largest land animals which have ever existed. And yet the same group includes the fleet little creatures no larger than a rabbit, already referred to. It would be quite impossible to do justice to this wonderful group without lengthy descriptions and numerous illustrations. They were the land animals *par excellence* of the Mesozoic age. The great size of many of them, the wonderful variety of horns and scaly armour with which many were provided, have well merited them the appellation “the dragons of their prime.” While the largest forms were adapted to feed on the vegetation of the period, they were kept in check by the scarcely less formidable carnivorous species.

Little, if at all, inferior to the Deinosaurs in abundance, variety, and size were the great marine reptiles belonging to the groups of the long-necked Plesiosauria and whale-like Ichthyosauria, which are

probably the most familiar of all fossil vertebrates. As the Deinosauers dominated the land, so they must have been supreme in the oceans. There is a striking analogy between these great marine reptilia and the whales among the mammals. Both attained enormous size, the Plesiosaurs rivalling the whales in this respect, both had their structure modified in a similar manner for aquatic life, both were descended from comparatively small land-dwelling ancestors.

The ancestors of the true crocodiles and alligators also existed in the Mesozoic seas—or, rather, on the shores, and were, on the whole, remarkably similar to the modern forms in their structure. In general appearance and in habits, they were probably scarcely to be distinguished from their living representatives. True tortoises also appeared as early as the Triassic period, with their typical shield-like armour. The snakes and lizards are scarcely known among fossil forms; but in the Cretaceous period there existed a group of marine reptiles closely allied to them—true “sea-serpents” in fact, and some of these, again, attained enormous size, probably sixty feet in length.

Far from the least remarkable feature in the history of the reptiles is their sudden extinction at the end of the Mesozoic era. In the Cretaceous period the Plesiosaurs and Ichthyosaurs were, it is true, already in a decadent condition, but they were replaced by the no less formidable sea-snakes. The Deinosauers were represented by their largest forms, and the flying reptiles likewise included species measuring no less than twenty-seven feet across the wing. The reptiles, in fact, were undisputed masters of air, sea, and land. Yet, without any obvious cause, all these dominant groups died out simultaneously, leaving, at the dawn of the Tertiary era, only the same contemptible group of “creeping things” which are the reptiles of to-day.

The history of the birds is very lightly sketched by their fossil remains. What there is of it, however, is of great interest. The earliest known bird, *Archæopteryx*, appears only in the middle of the Mesozoic era—in the Corallian rocks of Germany. Outwardly a typical bird in the possession of a perfectly normal coat of feathers, closer inspection readily reveals a number of deeply significant features. In place of a horny beak, the jaws are armed with simple rows of conical teeth, set in sockets in the normal manner. The wings possess three (possibly four) well developed grasping fingers armed with claws, as well as the one greatly enlarged digit which carries the wing feathers. But perhaps the most remarkable feature of all is the long graceful tail, which, instead of consisting of a simple bunch of feathers, as in all living birds, was rather the tail of a reptile, an extensive flexible prolongation of the back-bone, each joint of which carried a pair of feathers; surely as incongruous a combination of characters as nature ever produced. Indeed, in all characters in which *Archæopteryx* differs from the living birds, it assimilates to the reptiles, and points unmistakably to the reptilian ancestry of the former. Curiously enough, however, it was not to the flying reptiles that the birds were immediately related, but rather to the *Deinosaur*s, many of which presented several bird-like modifications. Up to the end of the Mesozoic era the birds retained the teeth in their beaks, but the other special marks of their reptilian descent speedily disappeared.

The history of the mammals is peculiar. We have already had occasion to refer to the quite extraordinarily mammal-like character of some of the early reptiles of the Permian and Triassic rocks which lead to a strong suspicion that the mammals are descended from them or their near relations. Now the earliest mammalian remains are, in fact, found in the highest part of the Triassic rocks; yet

they are, as far as the meagre evidence indicates, far from being the kind of mammal we should have expected to arise from the reptiles referred to. They are puny creatures, of very primitive type, about the size of a rat. And these little beasts are the only known forms throughout the Mesozoic era. During the early part of the Cainozoic era, in Europe and in America, the principal types of the mammalia appear in rapid succession, the majority of forms showing no special relationship to the little creatures already referred to, or any other indication of their ancestry. These facts have been explained on the assumption that we are dealing with a group of immigrants from some unknown region, whose advent was now made possible by the extensive geographical changes which marked the close of the Mesozoic and dawn of the Cainozoic eras. If true, until that unknown region is discovered, the history of the early evolution of the mammalia must remain unread.

When the mammals, then, for all practical purposes, first appeared in Europe and America, the great families were already marked out. Nevertheless, as by way of compensation, the story of their subsequent development is preserved with wonderful completeness, and we already know in great detail the history of the development of several important types.

The story of the horse has become classic. That familiar animal is one of the most specialised of the living mammalia, at least, as regards the structure of its limbs. The so-called "knee" of the horse is really its ankle or wrist, the "shin" or "cannon" bone being the first or "palm" joint of the single finger or toe which each limb possesses, while the hoof is of course the enlarged "nail" covering the last joint. A greater contrast could scarcely be imagined than that between this lower portion of the limb of a horse and the hand or foot of a man—which latter represent the normal mammalian type. Yet, as we trace



FIG. 12A.—DEVELOPMENT
OF THE SKULL OF THE
ELEPHANT.

After Andrews.

1. *Mæritherium*
—Middle Eocene.
2. *Palæomastodon*
—Upper Eocene.
3. *Tetrabelodon*
—Miocene.
4. *Tetrabelodon*
—Miocene and Pliocene.
5. *Elephas*
—Pliocene and Living.

FIG. 12B.—DEVELOPMENT OF
THE LIMBS AND TEETH OF
THE HORSE.

1. *Orohippus*—Eocene.
2. *Meshippus*—Miocene.
3. *Miohippus*—Miocene.
4. *Protohippus*—Pliocene.
5. *Pliohippus*—Pliocene.
6. *Equus*—Living.

N.B.—There should really be a gradual increase in size from 1 to 6 as noted in text.

the ancestors of the horse back stage by stage through the successive stages of the Cainozoic rocks, we find the specialisation of its limbs becoming gradually less marked till an almost perfectly normal type is reached, in a manner which is conveyed much more clearly by the accompanying illustration than it could be by any description. (See fig. 12b.) Along with these modifications in the limbs other changes proceeded; the size of the animal, which, to begin with was no larger than a collie, gradually increased, and, more notably, the teeth gradually increased in complexity from a very simple form to their present highly specialised condition.

More recently the history of another very specialised group of mammals has become very completely known—that of the elephants. Until a few years ago we only knew the latter part of their story, because the earlier history was buried in the rocks of Egypt. The elephant shows its specialised character partly in its great size, but more particularly in its highly modified teeth and jaws. Besides the pair of enormously developed teeth which form the tusks of the ordinary elephant, there is at any one time on one side of each jaw only one other large tooth to be seen, or at most a portion also of a second one. Nevertheless the size of each tooth is such that it almost completely fills the side of the jaw; and the complexity of the teeth is commensurate with their size. The “crown” is enormously high, and, instead of bearing merely a few tubercles on the surface, as a normal tooth, these are modified into large transverse vertical plates ranged compactly one behind the other to the number of over twenty, the whole forming the most efficient tooth for grinding vegetable material that Nature has ever devised. Again, though but one tooth at a time appears on each side of the jaw, the animal during its life has several such teeth successively in the same position. These successive teeth, however, do not represent successive “sets” in the proper sense, but

are all members of the one permanent set, which, unable from their enormous size to appear simultaneously, have been forced to become successional. Traced back to the Eocene rocks of Upper Egypt, the elephants are found to have their descent from a small animal which has been named *Moeritherium*, a creature about the size of a pony, with an almost perfectly typical set of low-crowned tuberculate teeth, and no tusks more striking than those of a modern boar. In the later Eocenes, larger forms occur with more prominent tusks (in both lower and upper jaws), with the "front" or incisor teeth already obliterated, and the "chin" of the lower jaw elongated in the direction of the forwardly-projecting tusks, so as to form, with them, a kind of "spade." Evolution continued in the same direction to the early Miocene period, when the chin was extraordinarily elongated, and the teeth larger and correspondingly less numerous. Subsequently the chin became again reduced, and the nose began to develop into the familiar "trunk," while the line of descent leading to the modern elephants branched off in forms possessing tusks only in the upper jaw. All the while the teeth grew larger and more complex, the tusks in particular became enormously developed, as also the trunk, till the line reached its maximum development in forms including the recently extinct Mammoth, some of which were much greater in bulk than any living elephant.

Finally, one other line of mammalian descent may be briefly referred to—that of the deer. This line presents many features in common with that of the horse, to which it is somewhat closely allied. The teeth present a practically identical evolution, albeit it has never reached so advanced a stage. The limbs also have specialised in a similar manner, with, however, this important difference: that instead of only one digit having persisted, *two* are preserved; but this pair of digits has almost

completely fused together, thus giving the same effect as in the horse, and exemplifying the oft-repeated truth that Nature may attain the same end by quite diverse means. It is to the history of the antlers, however, that we wish to refer. The earliest known deer occur in the upper Eocene, but are quite devoid of antlers; and not till the later Miocene period were these developed. When they did appear they were quite simple in form, with a single prong or "tine." As we trace the deer through their later development we find the number of tines gradually increasing, and the whole antler becoming larger and more complex, till it reached its maximum in the magnificent crown of the Deer found fossil in the Irish peat-bogs, with antlers ten feet across. Now, as everyone knows, this history of antler development is repeated by every deer in the course of its own life. Its first pair of antlers is simple, but each successive pair becomes more complex till it attains complete maturity and becomes a royal stag. Here we have a striking illustration of the fact that an animal, in the course of its development, repeats to some degree the stages of evolution through which its ancestors have passed—it "climbs its family tree"—and the study of development, Embryology, materially aids us, therefore, to supplement and interpret the fragmental palæontological history of life.

Here we must conclude these brief "chapters" out of the vast history of the earth, with the hope that they may stimulate the reader who has come thus far to go a little further.

THE END.

INDEX

	PAGE		PAGE
Acids, organic, in soil	57	Cullin Hills, Skye	52
Ammonites	120	Currents in oceans	71
Amphibia, first occurrence of ..	123	Danube, sediment carried by ..	56
— relation to fishes	124	Darwin, Sir G., on tides and	
Antlers, history of, in deer ..	133	rigidity of earth	36
Antrim, volcanic rocks	114	Deep sea	75
Archæopteryx	123	— life of	76
Arran, volcanic rocks	114	Deer, history of	132
Atlantosaurus	125	Deinosaurs	126
Balance of continental masses ..	96	Deltas, formed in lakes	55
Basalt	52	Denudation	69
Ben Lawers, section of	91	— estimated from	
Birds, fossil	123	folds	92
Bivalves (Pelecypoda)	120	Depth of Sea, distribution of	
Bombs, volcanic	49	sediments	71
Bothnia, Gulf of, movement of		Deserts, origin of	62
land	88	Devonian rocks	109
Brachiopoda, fossil	119	Dip of rocks	88
Bridlington Bay, encroachment		Disintegration of rocks	57
of sea	68	Dolomite, origin of	75
British Isles, geological map of	104	Dykes	51
— submerged		Earth, weight of	24
plateau of	70	— compared with surface	
Brontosaurus	125, 126	rocks	26
Cader Idris, volcanic rocks of ..	103	Earth-movements, cause of ..	96
Cainozoic	100	— in N. W.	
— mammalia of	129	highlands	103
Cambrian rocks	106	Earthquakes	36-40
Carbonic acid, action on rocks ..	64	— accompanying	
— in sea water	77	eruptions	28
Carboniferous rocks	110	— displacements of	
Cemeteries, weathering ex-		ground in	37, 86
hibited in	63	— effects of	36
Cephalopoda	120	— extent of move-	
Chalk period, geographical		ments in	39
conditions	112	— recording instru-	
Chalk, origin of	78	ments	38
Circumference of Earth, early		Echinodermata	120
measures	5	Elephants, history of	131
Climatic changes in Cainozoic ..	114	Elevation of land, proofs of ..	81
Coal Measures	110	Eocene period, geographical	
— as proof of		changes	113
subsidence	83	Estuary, deposits formed in ..	55
Comets	21	— of Lower Oolites	112
Cone of volcano, origin of	32	— of Lower Cretaceous	112
"Continental" periods of		Faults	92
Britain	105, 110, 113	— rate of formation of	93
Cooling of lava and size of		Fishes, history of the	122
crystals	49	Folding of rocks	89
Copernicus, discovery of true		Footprints, earliest known	
nature of Solar System	6	fossil	123
Corals, fossil	118	Footprints in Triassic rocks ..	111
— "precious"	119	Foraminifera, fossil	118
Coral-reefs	73	— in deep-sea ooze	76, 77
Cretaceous reptiles	127	Fossils as guides in arrange-	
Crevasses, engulfing moraines ..	61	ment of rocks	99
Crinoids (Sea-lilies)	121	Fossils, distribution of	116
Crocodyles, fossil	127	Frost, action on rocks and soil	53
Crystalline rocks	45	Gabbros	52
Crystallisation of lavas	49	Gastropoda (Univalves)	120
Cumbræ—Lion Rock	51		

	PAGE
Geological Map of British Isles	104
Glacial period	114
Glaciers	60
— erosion by	61
Glen Tilt, Hutton's observa- tions in	47
Grampian hills, rocks of ..	105
— structure of	90, 91
Granite	44
— microscopic section of ..	45
— weathering of	64
"Hag-fish," fossil	122, 123
Heat as cause of volcanic action	34
— of earth's interior	27
— solar, in destruction of ..	57
— rocks	57
Hipparchus, estimate of sun's distance	6
Horse, history of	130, 131
Hutton, the igneous origin of granites	46
Hylæosaurus	125
Ice, action on rocks and soil ..	58
Ice-age	114
Ichthyosauria	126
Iguanodon	125
Internal heat of earth	35
Interior of earth, probable condition	41
Joints, importance in marine erosion	69
Jupiter	11-14
— belts of	12
— temperature of	12, 13
— varying rotation	13
Krakatoa, eruption of	30
Lakes, deltas formed in	55
Lake District, volcanoes of ..	108
Land surfaces sunk below sea ..	84
Land-vertebrates, unknown origin	123
Lava, flow-structure in	48
— microscopic structure of ..	45, 48
— types of	49
— Vesuvian, nature of	52
Lavas, varying composition of ..	52
Leasowe, submerged forest	83
Level of land, changes of	81
Lewisian rocks	103
Liassic Sea	112
Life in early rocks	117
Lime in ocean, source of	73
Limestone, origin of	73
Lion Rock, Cumbræ	51
London basin, section of	91
Magma	53
Magnesian limestone, origin of ..	75
Mammalia, origin of	124, 128
Mammoth	132
Mars	9-11
— atmosphere of	11
— canals of	10
— snow-cap of	10
Martinique, history of erup- tions in	27

	PAGE
Meanders, action of rivers in ..	66, 67
Mesozoic	100
— reptiles	125
— rocks	111, 112
Metamorphism	94
Meteorites	21
Miller, Hugh, on fossil fish ..	123
Millstone Grit	110
Miocene, earth-movements in ..	113
— volcanic activity in	114
Mississippi sediment carried by ..	56
Mœritherium	132
Molten stage of all rocks	53
— of earth's crust	54
Moraines	61
Mountains, disintegration of rocks	59
— soil absent from	59
— variation of tem- perature	59
Mountain ranges, structure of ..	90
Movement of land, rate of	85
Mud, origin of	74
Mull, volcanic rocks	114
Nebulæ	20
— evolution of	22
— relation to comets and meteorites	22
Neck, volcanic	51
Neptune, discovery of	8
"Neptunists"	46
North Sea, deposits in	70
North Wales, raised beaches of ..	82
North-West Highlands, rocks of ..	103
Nuovo, Monte, history of	32
Old Red Sandstone	109
Old Red Sandstone, fish of	123
Ooze of deep sea	76
Ordovician period, land and sea of	107
— rocks	108
— volcanoes	108
Organic acids in soil	57
Outer Hebrides, rocks of	103
Palæontology, bearing on evolution	116
Palæozoic	100
Paris, foraminiferal limestones ..	118
Pelecypoda (Bivalves)	120
Peleë, Mount, eruptions of	28
Pennine Chain, origin of	110
— structure of	90
Permian rocks	111
Planets, distance from sun	8
— masses	8
— densities	8
— minor	8
— origin of	22, 23
Pleistocene	114
Plesiosauria	126
Pliny, account of eruption of Vesuvius	30
Pliocene	114
Plutonic rocks	50
"Plutonists"	47

	PAGE		PAGE
Pre-Cambrian period, length of	117	Stars, evolution of	22
Preliminary tremors of earth-		— types of	20
quakes	39, 40	Star-fishes	121
—evidence of rigid		Steam in volcanic eruptions	33
interior of earth	40	Stratified rocks	42
Pterodactyls (flying reptiles)	125, 127	— table of British	100
Ptolemaic system	6	Stromboli	31
Radiolaria in deep-sea deposits	79	Submerged forests	83
Raised beaches	82	Subsidence of land, rate of	85, 87
Recapitulation in development	133	Subsoil	57
Red Clay	79	Succession of rocks, historical	
Reptiles, dominance of	124	order	97
— early forms of	124	Sulphurous gases in eruptions	23
— extinction of	127	Sun	14-18
Rhyolite	52	— composition of	17
— microscopic section of	45	— distance of	7
Rivers, action of	65	— gaseous condition	16
— changes of course	67	— red flames (prominences)	15
— lowland	66	— rotation of	16
Roches moutonnees	61	— spots on, nature of	15
Roots, aid in formation of soil	57	— telescopic appearance	15
Salts of sea, source and fate of	75	— temperature of	14
Salt in Permian and Triassic		Survival of simple organisms	119
rocks	111	Sweden, movement of land in	88
Sand, origin of	74	Temperature of Earth's interior	27
Schists, etc., of Grampians	106	— gradient	27
Scree	59	— variation affecting	
Sea-bed, distribution of sedi-		rocks	57
ments on	71	Terrigenous deposits	71
Sea, erosion of coast by	68	Thrust planes	93
Sea-lilies (Orinoids)	121	Tidal currents	72
Sea-urchins	120	Tides proving rigidity of earth	36
Sedimentary rocks, derived		Torridonian sandstones	105
from igneous	53	Transport by rivers	65-68
relation to igneous	74	Triassic rocks	111
Sediments, distribution of	71	Tundras, origin of	58
Sediments prove slow subsi-		Unconformity	101, 102
dence	86	Univalves (Gastropoda)	120
Seismographs	33, 39	Uranus, discovery by Herschell	8
Seismology	38	Valleys sunk below sea	84
Sharks, among earliest fish	122	Vertebrata, knowledge of fossil	121
Shooting-stars	21	Vertebrates, unknown origin	
— in deep-sea deposits	80	of land	123
Silurian rocks	108	Vesuvian lava, nature of	52
Simple organisms survive	119	Volcanic rocks	50
Skye, Cullin Hills	52	— of Old Red Sand-	
— volcanic rocks	114	stone	109
Slate, origin of	94	Volcano, ideal section of	31
Snow, protecting rocks	60	— origin of cone	32
Snowdon, volcanic rocks of	108	Volcanoes	27-35
Spectroscope, applied to study		— British	50
of Sun	17	— dissected	51
Soil, origin of	56	— distribution of	34, 35
— waste of	56	— of Miocene period	114
Solar heat, in deserts	62	— of Ordovician period	108
— in destruction of		— relation to mountain-	
rocks	57	ranges	33
Solar System, table of elements	8	Water given out by volcanoes	34
— unity of	18	Waterfalls, action of	66
Solution of shells in sea	77	Waves, action on cliff	68
Somma, Monte	33	Weathering of rocks	63
South-east England, section of	91	— exhibited in cemeteries	63
St. Pierre, destruction of	29	Werner, the origin of Granites	46
Stacks, origin of	69	Wales, rocks of	106-108
Stars, distances of	19	— volcanoes of	108

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